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Public Roads

A JOURNAL OF HIGHWAY RESEARCH

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FEDERAL HIGHWAY ADMINISTRATION

Public Roads

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CONTENTS

Articles

Experience to Date with Impact Attenuators, by *John G. Viner* 209

Fatal Accidents on Completed Sections of the Interstate Highway System, 1968–70, by *Harold R. Hosea* 219

U.S. Interstate Highway Interchange Milepost Designators—An Investigation of Efficient Coding Methods, by *Adrienne A. Whyte* 222

Departments

Digest of Recent Research and Development Results 224

Highway Research and Development Reports Available From National Technical Information Service 226

Map of Interstate and Defense Highways—Status of System Mileage, June 1971 228

Federal Highway Administration publications Inside back cover

COVER

Veteran's Memorial Bridge across Rock River, Janesville, Wis. (Photo courtesy of State of Wisconsin Department of Transportation, Division of Highways.)

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Experience to Date with Impact Attenuators

Reported by JOHN G. VINER,
Leader Protective Systems
Group, Structures and
Applied Mechanics Division

BY THE OFFICE OF RESEARCH

Last year approximately 20,000 people were killed in accidents in which their vehicle left the road. Recent experience verifies that off-road accidents are the leading source of fatalities on Interstate and other freeways. In addition, more than 40 percent of Interstate fatal accidents involved a rigid roadside obstacle.

Among the efforts to reduce this toll has been the development and installation of impact attenuators (sometimes called crash cushions or energy-absorbing barriers) in a number of States at locations such as exit ramps on bridges. This report contains current information on research in this area.

Introduction

COLLISIONS with fixed objects beside the highway are the leading cause of deaths in Interstate and other freeway accidents (*1*, *2*).[1] To reduce these deaths, experimental impact attenuators (also called crash cushions or energy-absorbing barriers) have been installed at elevated exit ramps in a number of States. These devices have, in fact, reduced the number of fatalities and hospitalizing injuries experienced at these rigid obstacles, and several barrier designs are now considered operational. Research, under way to develop new types of energy-absorbing barriers and to improve existing designs, may further reduce this primary cause of fatal accidents.

Recent developments in crash cushions are discussed here, with emphasis, for the most part, on concepts rather than details. Interested readers may obtain detailed information from the references. Because a good idea of the scope of this work can be obtained from references (*3*, *4*) and (*5*), no attempt will be made to list all current research in this area.

Background

In 1968 and 1969, 52 percent of fatal accidents on Interstate highways involved cars which ran off the road (*1*). A fixed object was struck in more than four-fifths of these accidents. Although approximately 20,000 people died in accidents of this type in 1970, (*6*), on a vehicle-mile basis substantially lower fatality, injury, and accident rates occur on the Interstate System than on comparable conventional highways (*7*).

In recent years highway engineers have developed several ways to help reduce the toll taken by roadside hazards. One way, of course, is to have a clear area beside the road. Another method is to use frangible or breakaway features for sign and luminaire supports. Careful consideration of warrants and details for guardrails (the guardrail itself is a hazard) provide additional protection for motorists.

Several types of experimental barriers (*8*, *9*) have been installed to handle near head-on impacts at gores. These devices are being monitored under the national experimental evaluation program—with the cooperation of the States and Federal Highway Administration (FHWA) field offices.

Criteria

The criteria presently used by FHWA in developing (*5*) and evaluating new devices (*10*) are as follows:

1. Vehicle-weight range—2,000 to 4,500 lbs.
2. Vehicle speed—60 m.p.h.
3. Impact angle—up to 25° as measured from the direction of the roadway.
4. Average permissible vehicle deceleration—12 g's maximum, while preventing actual impacting or penetration of the roadside hazard.
5. Maximum occupant deceleration onset rate—500 g's per second.

---

[1] Italic numbers in parentheses identify the references listed on page 218.

Installations meeting these criteria should provide enough protection so that in the majority of high-speed collisions, one would survive. For barriers which just meet the 12-g requirements, injuries to unrestrained occupants were anticipated in most high-speed collisions (*5*).

Figure 1 shows the distribution and frequency of vehicle weights determined in a 1968 Michigan study (*11*). More than 80 percent of the vehicles weighed between 2,000 and 4,500 pounds. Although 15 percent weighed more than 4,500 pounds, all 500-pound increments over 4,500 were less than 1 percent. All road situations, however, are not represented by figure 1. For example, in areas with heavy pickup truck and camper registrations or heavy-truck traffic, crash cushions designed to withstand a greater weight range may be warranted. At the other end of the weight range, sales of compact and subcompact cars now take about one-third of the total U.S. market.

Figure 2 illustrates the distribution of impact speed in 5,237 single-vehicle accidents on Michigan freeways (*11*). Since impact speed was obtained from estimates made by police officers on accident reports, unreported accidents were not included. Although 80 percent of these accidents occurred at speeds estimated at less than the 70 m.p.h. limit, more than 55 percent were estimated in excess of 60 m.p.h.—the evaluation speed in the criteria. Of the 640 fixed-object fatal accidents in California and 165 in Texas reported by Olson (*12*), 60 percent were estimated at speeds in excess of 60 m.p.h. Based on this sample, Olson recommended that full-scale dynamic tests be conducted at 65 to 70 m.p.h., rather than at 60 m.p.h. suggested by the Highway Research Board Committee on Guardrails and Guide Posts in 1962 (*13*).

The 25° maximum impact angle provides the same 60 m.p.h., 25° test condition used for traffic railings. Because most current installations are immediately followed by traffic railings, the same glancing impacts experienced by railings are possible on the crash cushion. Therefore, it seems logical to attempt to develop crash cushions that meet the same glancing impact criteria required of traffic railings.

Figure 3 compares the relationship between average vehicle deceleration in head-on impacts and probability of injury to unrestrained occupants. Olson (*12*) determined this relationship with the aid of accident data reported by Michalski (*14*), who developed a photographic guide for appraising the severity of vehicle damage. Information in figure 3 indicates that it is desirable to design barriers to a lesser deceleration level than the criteria's 12-g limit. Several existing devices result in 6 to 8 g's or less in most collisions.

Accident Experience

Documented accidents are the best measure of a barrier's safety performance. Under a national experimental evaluation program,

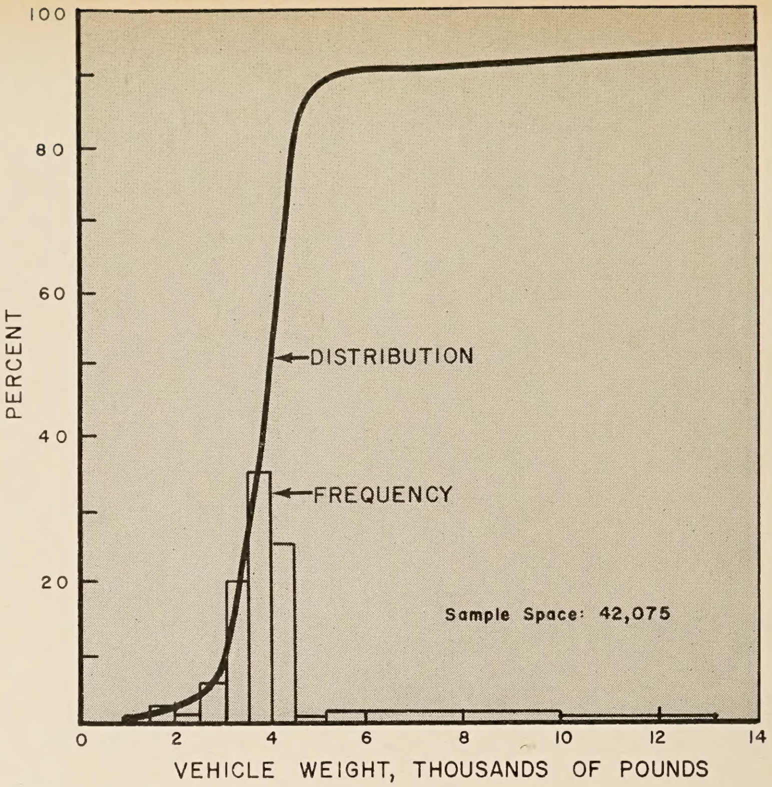


Figure 1.—Vehicle weight distribution from selected Michigan Freeway data (1968).

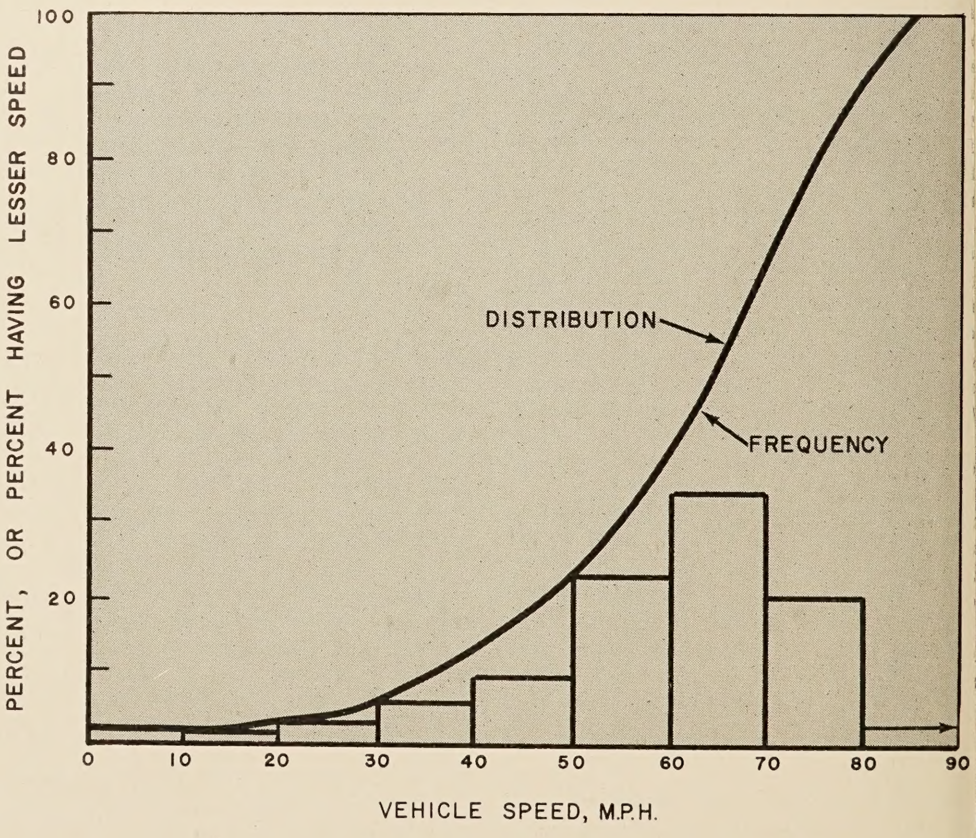


Figure 2.—Estimated impact speed in 5,237 passenger-car single-vehicle accidents.

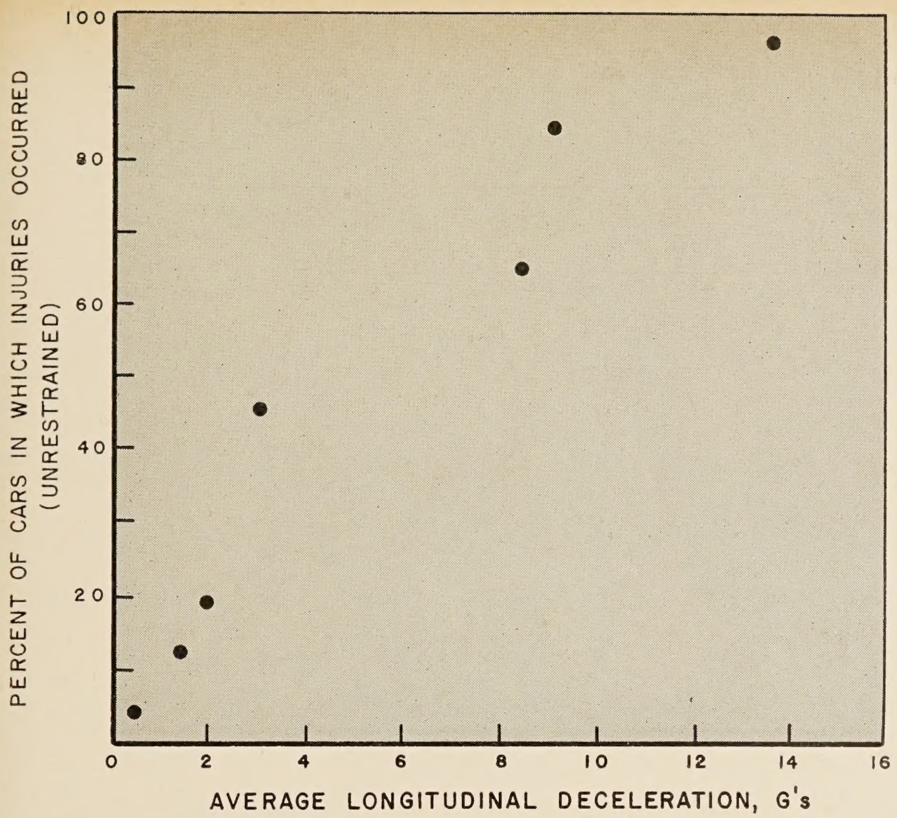


Figure 3.—Injuries versus average vehicle deceleration—head-on impacts.

FHWA, with the cooperation of 38 currently participating States, is gathering accident data on barriers. From data on 129 accidents recorded by April 15, 1971 (table 1), the percent of accidents in which fatalities or injuries may be expected has been predicted at a 90-percent confidence level. Note that this accident data sample, however, is too small to attach statistical significance to the performance record of each device.

Careful analysis of these accident reports indicated that if the attenuator had not been present (table 2), hospitalizing injuries or fatalities could have been expected in 30 accidents. The effectiveness of these barriers is shown in that only three hospitalizing injuries and one fatality occurred in these 30 cases.

Data in tables 1 and 2 do not include hi-dro cell clusters (an array of individual cells without *fish scales*), which were designed for speeds under 45 m.p.h. In the 60 accidents known to us to date involving these barriers, one fatality, eight injuries, and 51 property-damage-only collisions occurred.

The following tabulation (*15*) shows that 4.4 accidents per year occurred at gores where impact attenuators were installed:

Sites examined	28
Accidents	95
Total months of exposure	260
Accidents/year of exposure	4. 4

Most installations were in existing gores rather than in new construction. In many installations the attenuator was positioned in front of the existing parapet nose (fig. 4). This, of course, reduces the amount of maneuvering room available in the gore area and, as a result, increases the number of accidents that occur. In new construction and in some existing gores, the gore can be designed or rebuilt (fig. 5) so that the attenuator occupies essentially the same space as a conventional bridge parapet nose. In this case no increase in the number of accidents would be expected. Provision of such space is now required for elevated-exit ramps in Federal-aid projects (*10*). It should also be noted that many of these initial installations of impact attenuators are at known high-accident locations. Thus, additional installations and accident experience may result in an accident frequency less than 4.4 per site per year.

An analysis of the point of impact and angle of impact for the 86 crash-cushion accidents is given in table 3. To facilitate comparison (table 4) of these results with data available on 47 California freeway fatal accidents involving gores (*16*), a flat angle was defined as one estimated to be less than 10°. The agreement between the two sets of data is surprisingly good. They indicate that about three-fourths of the accidents occur on the nose of the device and one-fourth on the side. Four-fifths of the accidents occurred at angles of less than about 10° and one-fifth at angles in excess of 10°.

Most steel-drum attenuators are similar to those shown in figures 5–11. Figure 6 shows a head-on crash test into a steel-drum crash cushion with 4,500-lb. vehicle at 56 m.p.h. The 16.0-foot stopping distance corresponds to an average decleration of 6.5 g's. Figures 7 and 8 give the results of a 70-m.p.h. head-on collision in Houston, Tex. In this accident the vehicle stopped in about 17 feet for an estimated average deceleration of 9.5 g's. The unrestrained driver received a broken nose and rib; the unrestrained passenger, a broken collar bone. This was one of two hospitalizing injury accidents shown for this device in table 2.

Table 1.—Impact attenuator accidents

Attenuator	Accidents				
	Total	Fatal	Injury	Fatal plus injury	Fatal plus injury, 90% confidence limits
	Number	*Number*	*Number*	*Percent*	*Percent*
Steel drum	45	1	8	20	11—33
FIBCO	58	0	5	9	3—20
Tor-Shok	13	0	7	54	28—80
Hi-dro cushion	12	0	2	17	3—45
Dragnet	1	0	0	----------	----------
Total accidents	129	1	22	18	----------

Table 2.—Impact attenuator accidents judged likely to have produced fatalities or hospitalizing injuries if attenuator not present

Attenuator	Number of accidents				
	Total	Fatal	Hospitalizing injury	Minor injury	Property damage only
Steel drum	11	1	2	6	2
FIBCO	10	0	0	2	8
Tor-Shok	5	0	0	4	1
Hi-dro cushion	4	0	1	1	2
Total accidents	30	1	3	13	13

TABLE 3.—Analysis of 86 impacts involving crash cushions

Impact angle	Number of impacts		
	Nose	Side	Total
Head-on	31	3	34
Flat angle (≤10°)	27	7	34
Large angle (>10°)	10	8	18
Total impacts	68	18	86

TABLE 4.—Comparison of crash cushion experience with 47 California freeway fat accidents involving gores

Category	Crash-cushion accidents		Freeway fatal accidents	
	Number	*Percent*	*Number*	*Percent*
Angle of impact:				
Head-on	34	40	19	42
Flat angle (≤10°)	34	40	18	40
Large angle (>10°)	18	20	8	18
Location:				
Nose	68	79	35	74
Side	18	21	12	26

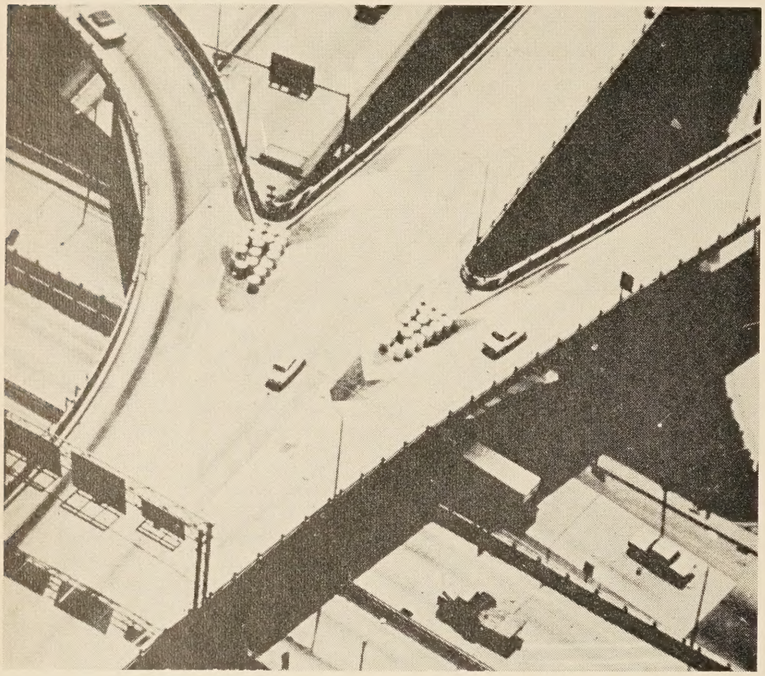


Figure 4.—Two Fitch Inertial barriers installed on an existing elevated structure.

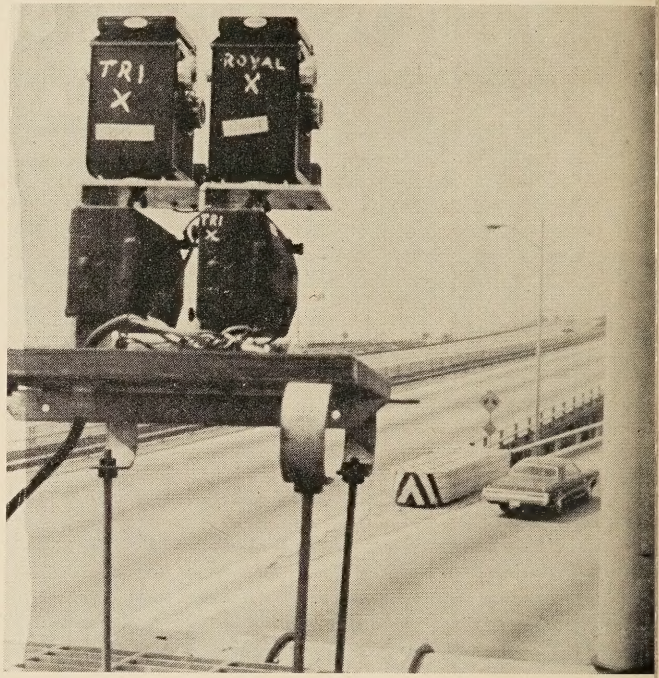


Figure 5.—Camera surveillance of a steel-drum barrie installed on an existing elevated gore.

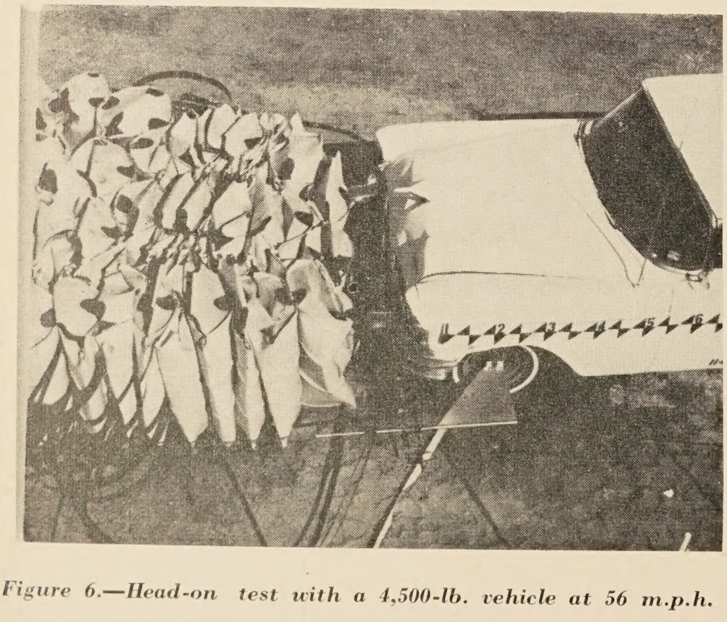


Figure 6.—Head-on test with a 4,500-lb. vehicle at 56 m.p.h.

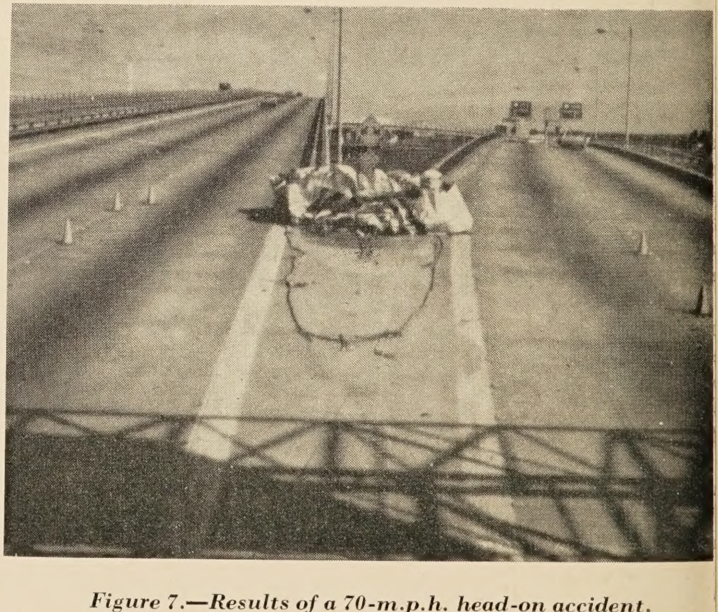


Figure 7.—Results of a 70-m.p.h. head-on accident.

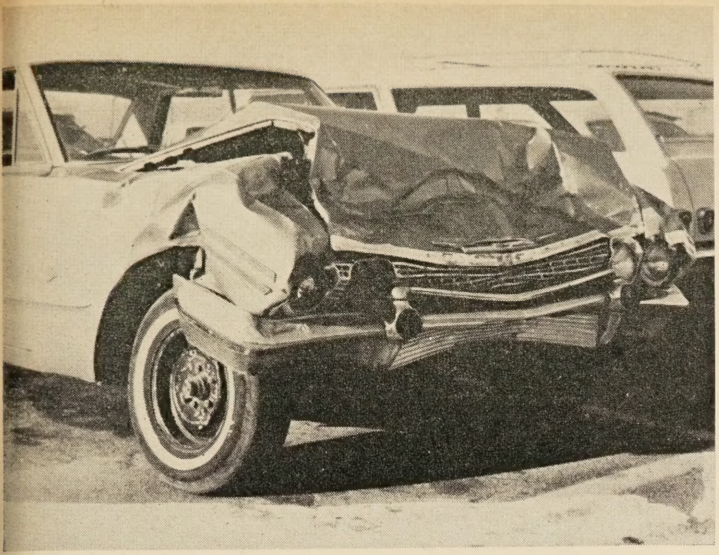


Figure 8.—Vehicle damage after accident shown in figure 7.

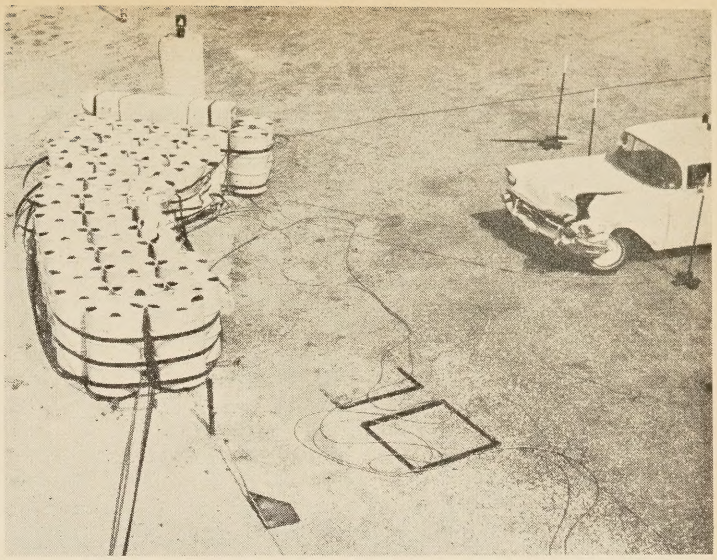
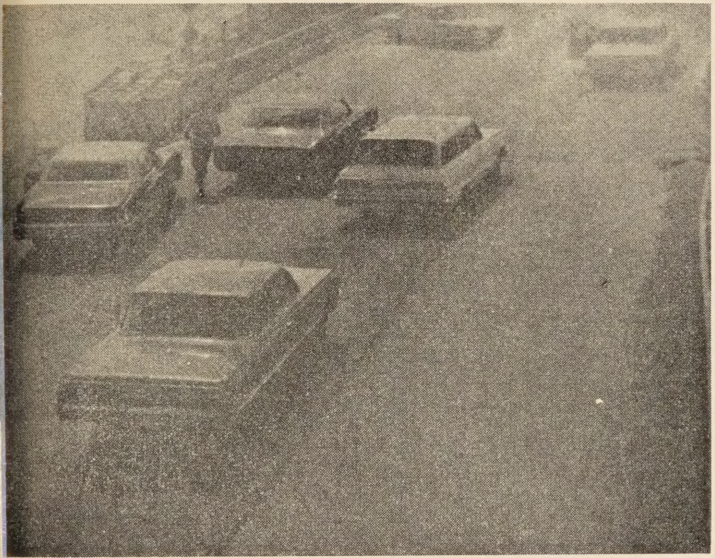


Figure 9.—41-m.p.h. test at 20° with a 3,900-lb. vehicle.



igure 10.—Seconds after an accident with a steel-drum barrier.

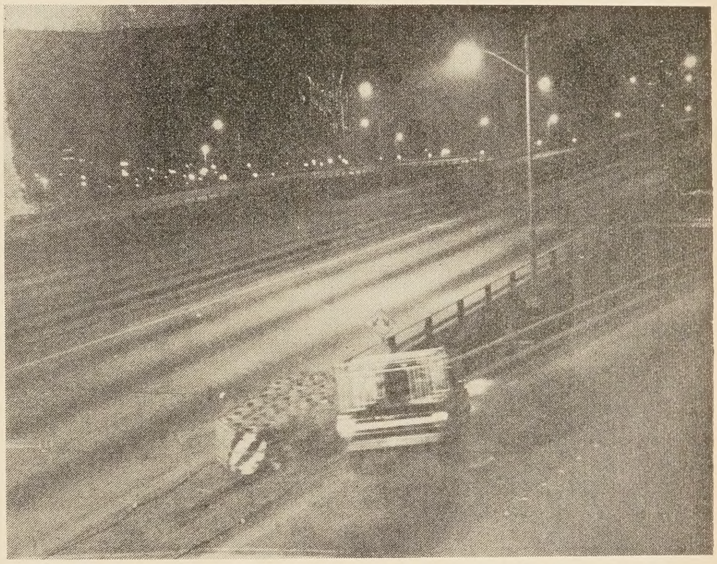


Figure 11.—An accident occurring with a steel-drum barrier.

The fatal accident involving a steel-drum arrier was head-on in a 3,700-lb. pickup ruck at approximately 42 m.p.h. Stopping istance was 7.5 feet for an average deceleraion of 7.4 g's. The unrestrained driver was atally injured when he collided with the igid steering column.

Figure 9 shows the results of a 41-m.p.h. npact at 20° with a 3,900-lb. vehicle. The ehicle *pocketed* in the barrier. Although the verage deceleration was 4.0 g's on an elevated ore, pocketing could result in a collision with following vehicle.

Figure 10, a picture obtained by surveilance using still and motion picture cameras ig. 5 (*17*)), shows an accident just after it appened. In this mishap the vehicle pocketed ightly toward the rear of the barrier, concting the rigid back-up wall, and then spinning out. Figure 11 shows a similar accident while it was occurring. Although no injuries were reported in either accident, efforts have been made to improve this aspect of the steel-drum barrier performance. One concept will be discussed in this report.

Figure 12 gives the results of a 50-m.p.h. crash test of a Fitch Inertial Barrier with a 3,500-lb. vehicle. This test involved a driver, wearing a conventional lap and shoulder harness restraint, crashing into the 21-foot-long barrier. (Two such barriers are shown in fig. 4.) Stopping distance was 27 feet for a 3-g average deceleration. The car was driven away after the impact.

Damage to a vehicle after an actual accident with this barrier, where the driver sustained minor head bruises, is shown in figure 13. Figure 14 illustrates typical barrier damage from another accident. As in many accidents with this type barrier, the vehicle can be driven from the scene (*18*).

Figure 15 shows a hi-dro cell unit in place, and figure 16 shows a similar unit after a 60- to 70-m.p.h. collision, with impact on the driver's side (*19*). The unrestrained driver sustained only cuts and bruises. Figures 17 and 18 illustrate the results of a head-on crash by a 4,600-lb. test vehicle traveling at 64 m.p.h. (*20*). Stopping distance was 17.3 feet, for an average deceleration of 7.9 g's.

Figure 19 shows a TOR-SHOK installation, and figure 20 shows a head-on collision into a barrier of this type by a 4,600-lb. test vehicle at 34 m.p.h. (*21*). Stopping distance was 5.9 feet (4.5-feet-barrier deformation and 1.4-feet-vehicle crush), for an average deceleration of 6.6 g's. Figures 21 and 22 show

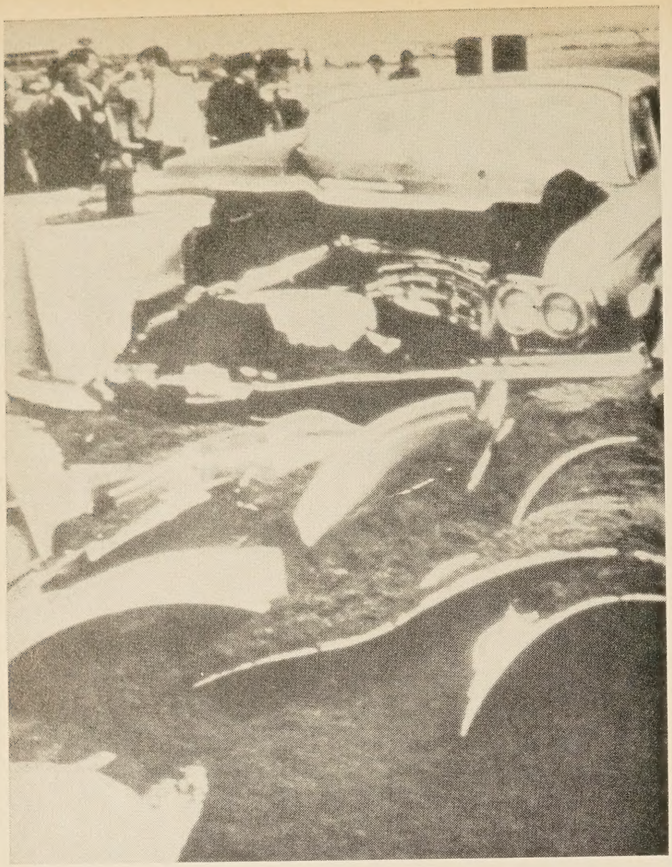


Figure 12.—50-m.p.h.-crash test with a 3,500-lb. vehicle against a Fitch Inertial barrier.

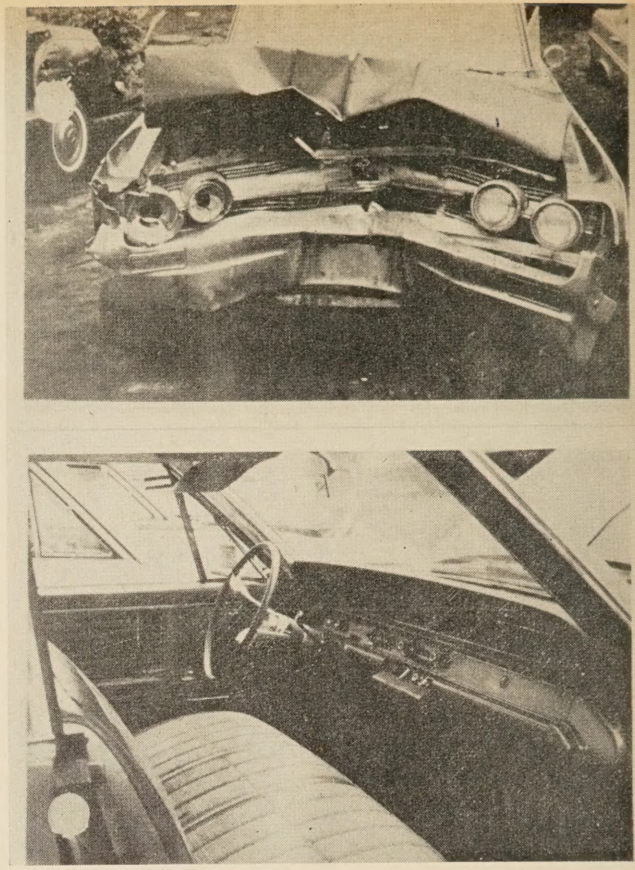


Figure 13.—Vehicle damage from an accident with a Fitch Inertial barrier.

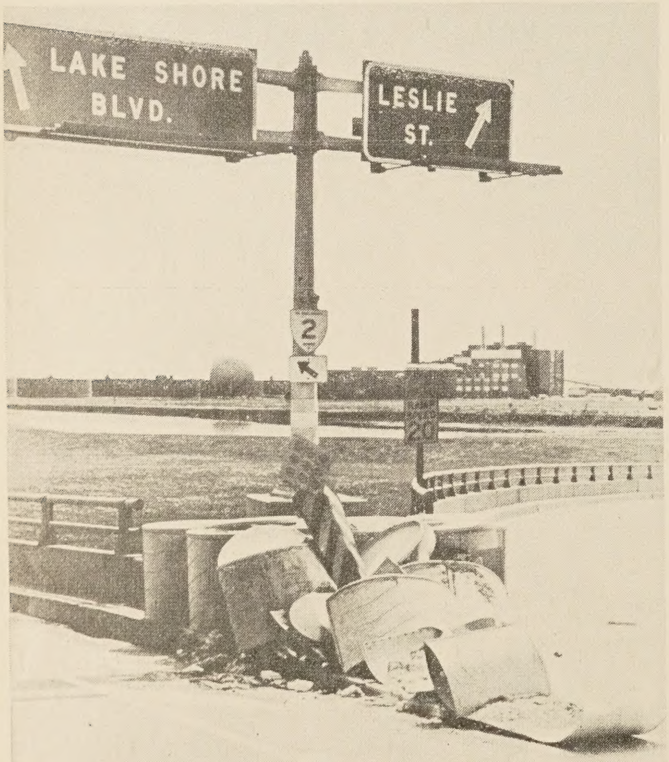


Figure 14.—Typical accident damage to Fitch Inertial barrier.

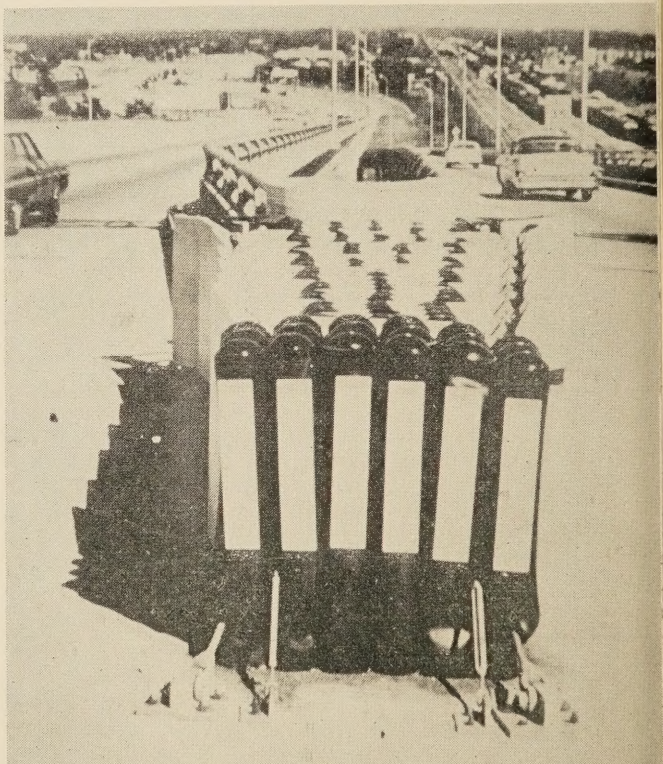


Figure 15.—Hi-dro cell installation.

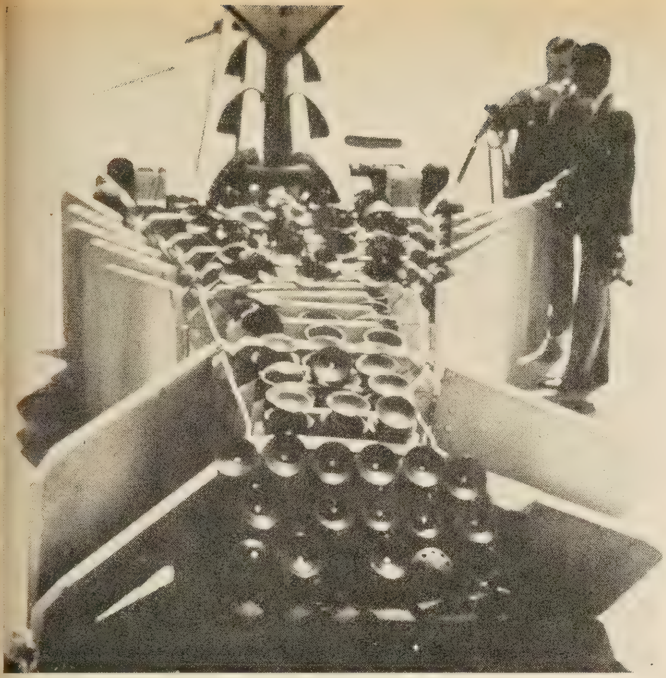


Figure 16.—Hi-dro cell barrier after a 60- to 70- m.p.h. side-on accident.

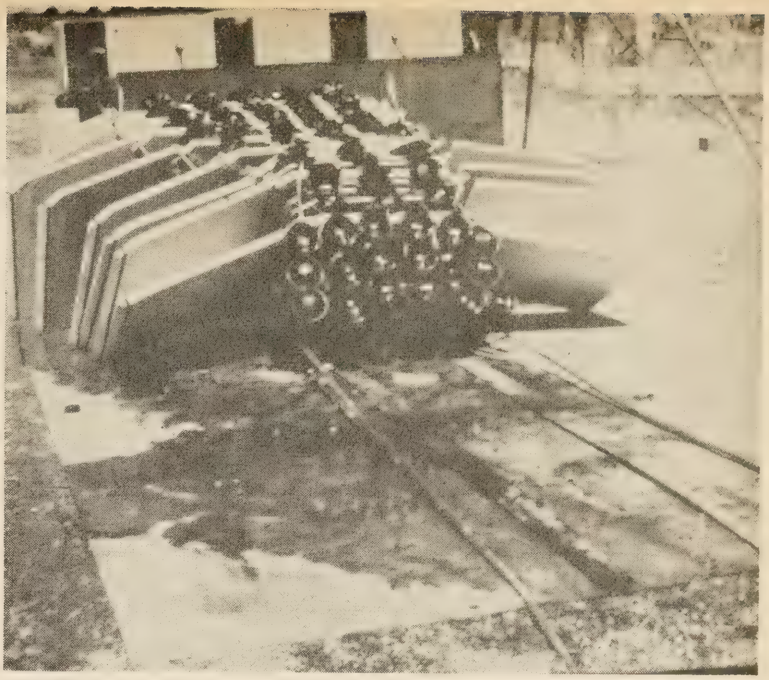


Figure 17.—Barrier after a 64-m.p.h. head-on crash test with a 4,600-lb. vehicle.

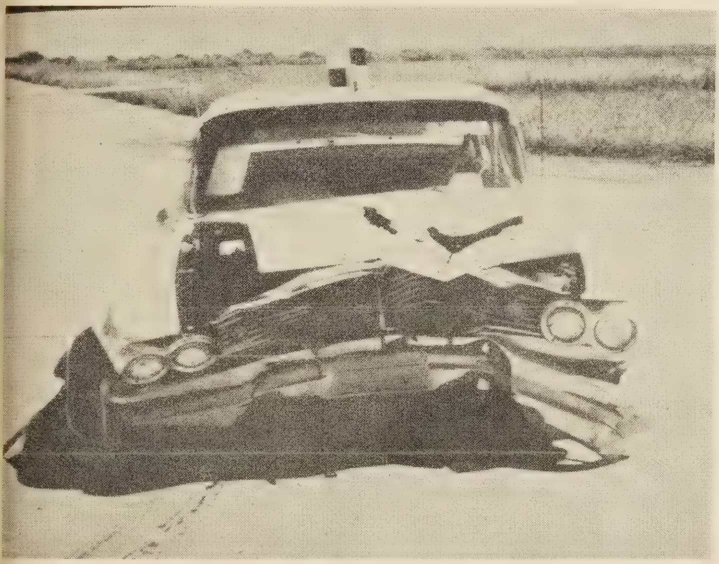


Figure 18.—Vehicle after impact shown in figure 17.

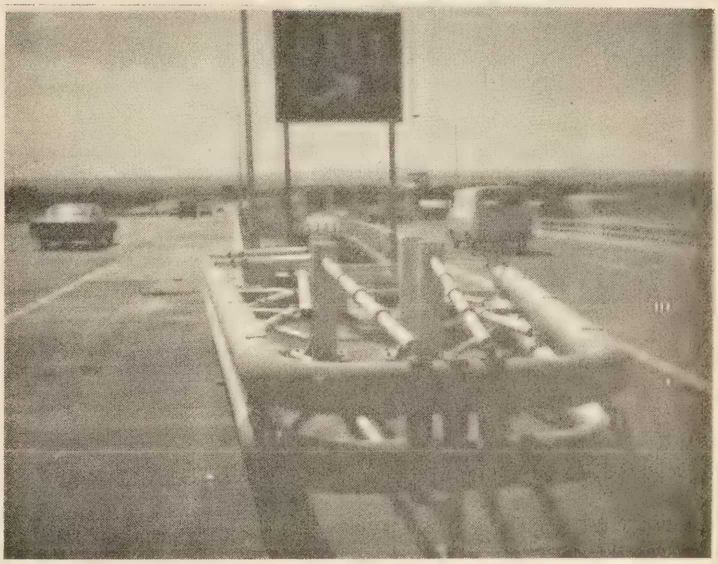


Figure 19.—TOR-SHOK installation.

he results of an accident estimated at 35 n.p.h. (*22*). Maximum barrier displacement vas 3.6 feet, and the unbelted driver suffered ninor injuries.

Generally, accident experience with these mpact attenuators confirms expectations of heir probable performance. Based on studies f the various designs and full-scale crash esting, an FHWA instructional memorandum *10*) stated:

"Testing and actual field experience indicate hat the steel drum, hi-dro cushion, and sand ontainer devices, at their present stage of evelopment, are serviceable hardware items offering the public significant protection from the hazards of fixed roadside objects on high-speed highways, particularly from those fixed objects found in gore areas. Therefore, devices of these three types, which are substantially similar in details to the forms and details that have been successfully tested, need no longer be considered as experimental features and may be included in Federal-aid projects just as any other item of highway hardware. The TOR-SHOK device is also not considered an experimental feature. However, its use is subject to the limitation set forth in Mr. Williams' November 13, 1969, circular memorandum that the locations for future installations be selected where impact speeds above 50 m.p.h. would not be expected (on urban viaducts, on roadways with restrictive alinement, etc.). Removal of these four types of devices from the experimental category as described above is not intended to indicate they have been perfected. The side-hit characteristics of these devices still leave much to be desired. And there is sentiment that the performance criteria should be made more demanding. But we have no indication that any of the devices mentioned here increase accident severity and there is evidence to the contrary.

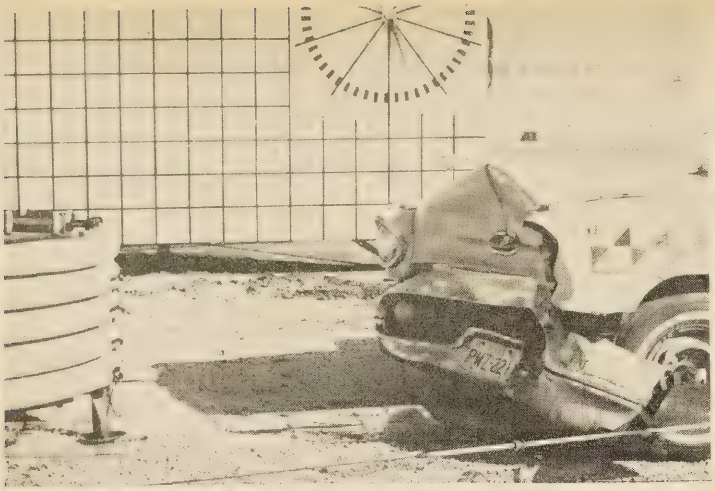


Figure 20.—TOR-SHOK test, head-on at 34 m.p.h. with a 4,600-lb. vehicle.

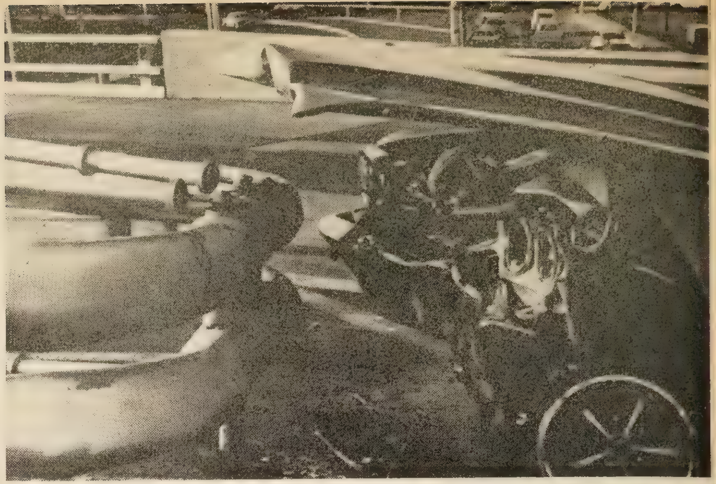


Figure 21.—Vehicle after a TOR-SHOK accident at about 35 m.p.

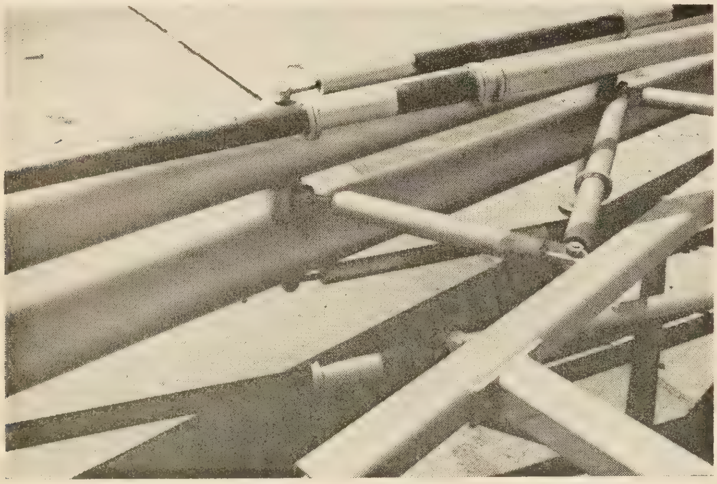


Figure 22.—TOR-SHOK after accident shown in figure 21.

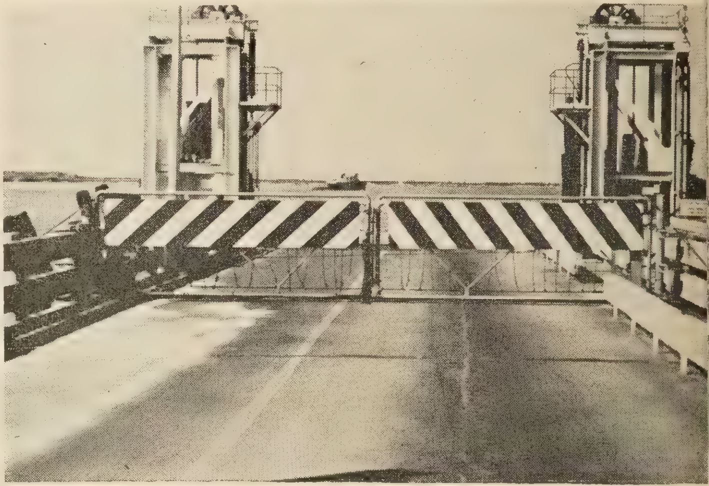


Figure 23.—Dragnet installation.

"(Field experience with hi-dro cell clusters—a limited number of individual cells without *fish scales*—developed specifically for use where traffic velocities are under 45 m.p.h., indicates that these devices also need not be considered experimental.)"

Figure 23 shows the only dragnet installation (*23*) presently known to us. This device, near Galveston, Tex., performed as designed in the only recorded accident—a 10-m.p.h. collision with a 2½-ton truck whose brakes had failed. Dragnet installations are being considered for sites such as the space between twin bridges and reversible lane control.

Research Under Way

A number of current Federal, State, and industry research studies are concerned with improving the performance of existing impact attenuators, developing new types, or increasing our understanding of the nature of vehicle-barrier collisions.

Figure 24 illustrates the hazard of the unshielded bridge pier in a median. Figures 25 and 26 show a steel drum designed for such locations by FHWA with the assistance of the Texas Transportation Institute (*24*). In this test a 4,200-lb. test vehicle that crashed into the barrier at 57 m.p.h. and 20° was successfully redirected. The dummy in the driver's seat was aimed at the center of the simulated bridge pier. The fendering system used in this design can also be used for steel-drum designs for elevated gores. It should be helpful in avoiding vehicle contact with the rigid back-up wall and in decreasing pocketing.

Initial studies of lightweight concrete crash cushions (*25*) concerned head-on impacts only. Studies sponsored by Florida (*26*) and FHWA have used plywood *fish-scale* panels to improve behavior in oblique impacts. Figure 27 shows a successful 60-m.p.h., 10-degree test with this design. To select a mix design, freeze-thaw and moisture-absorption tests are now under way on several lightweight concre materials. The behavior of this barrier is n presently known when it is fully saturate with water (about double dry weight) or th cardboard sonotubes have essentially disi tegrated with exposure to the environment, when it is partially saturated and frozen.

Goodyear Tire & Rubber Co. has examine the feasibility of crash cushions made of lor rows of discarded tires (*27*). A 42-m.p. head-on impact is shown in figure 28. Stoppi distance was 12 feet. No side impacts, howeve have been reported at this time.

Plastic foam has been examined as material for impact attenuators (*28*). Way State University is currently developing ne foam-barrier configurations under a Michiga highway planning and research (HPR) stud (*11*).

Analytical efforts have not been disregarde in research in this area. Under an FHW contract, Dr. Graham Powell of the Universit of California, Berkeley, has developed a computer program to predict the behavior of an automobile in a collision with a protective barrier (*29*). Large displacements and inelastic behavior are considered in the barrier structure. Initial studies of several barrier systems with this program have been very encouraging. Additional investigation, now under way, hopefully will result in detailed recommendations on the use of the program, and in definite conclusions on its accuracy (*29*).

Scale-model techniques have been investigated at the Denver Research Institute (*30*) —with very good results for the head-on test. Under a Colorado HPR study, investigators are using this technique to examine a new barrier developed at the Denver Research Institute.

Conclusions

Crash cushions are capable of significantly reducing the severity of a collision with fixed roadside obstacles. Accident experience with several of these impact attenuators has confirmed expectations of their probable performance. FHWA has urged the placement of these devices, especially in locations such as gores on bridges where they have proven useful.

Further research is under way to extend the list of roadside conditions where these barriers could be used. New types of barriers are being developed and efforts are being made to improve our knowledge of the nature of vehicle-barrier collisions.

ACKNOWLEDGMENTS

Much of the recent progress in this field was made possible through the close cooperation

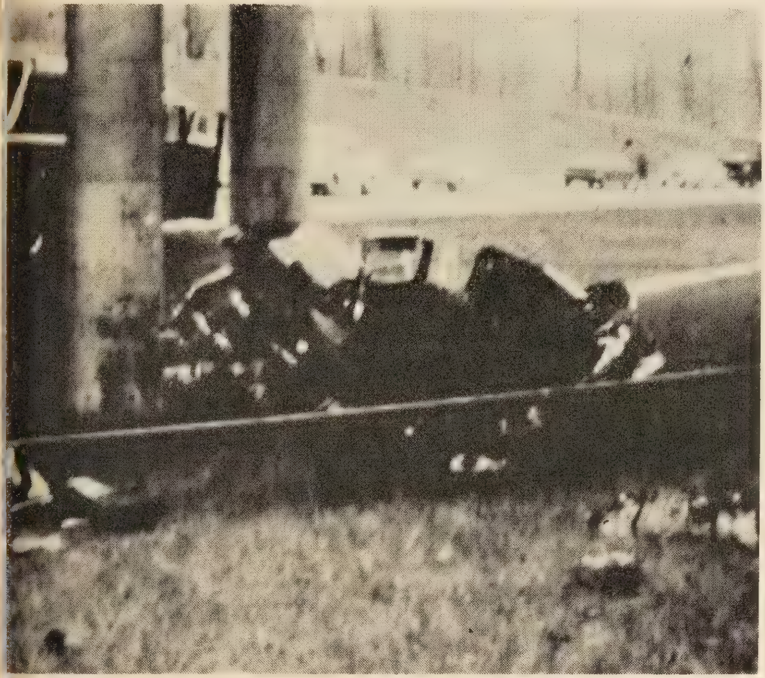


Figure 24.—Fatal collision with a median bridge pier.

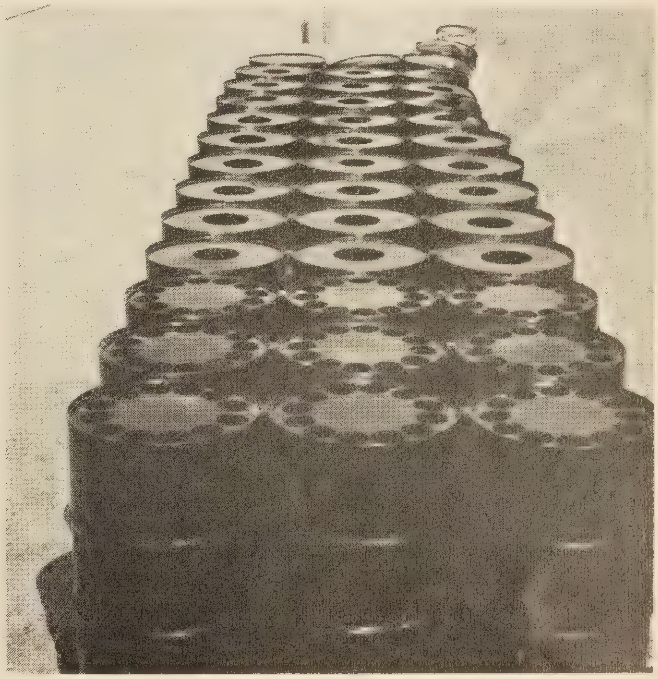


Figure 25.—A 57-m.p.h., 20° test with a 4,200-lb. vehicle of a barrier designed for median bridge piers.

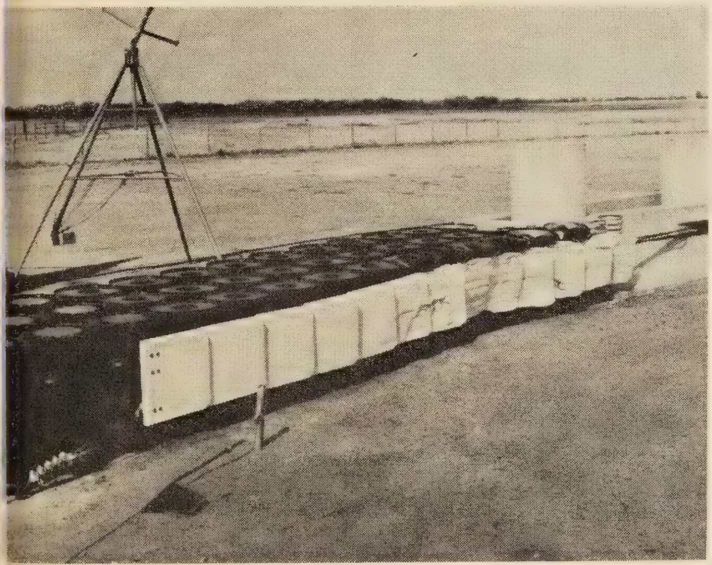


Figure 26.—Side of barrier after test shown in figure 25.

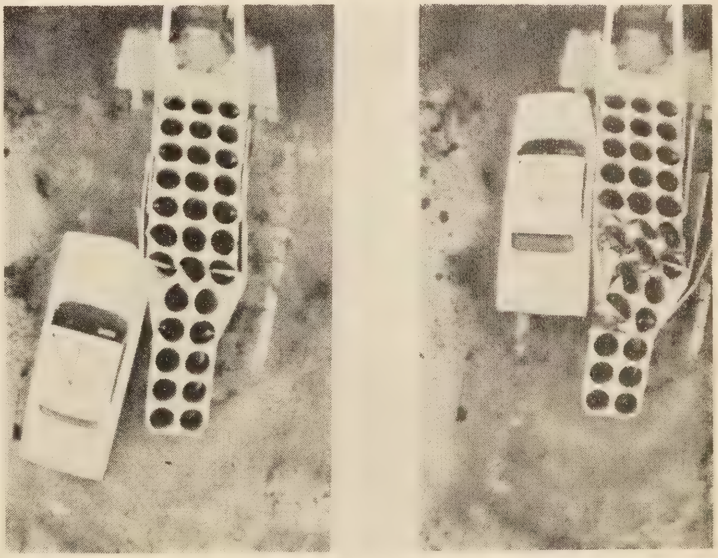


Figure 27.—60-m.p.h., 10-degree test of a lightweight concrete barrier.

of FHWA with State and industry engineers and research teams. Accident data on crash cushions were provided by the States in a cooperative experimental evaluation program with FHWA (*15*).

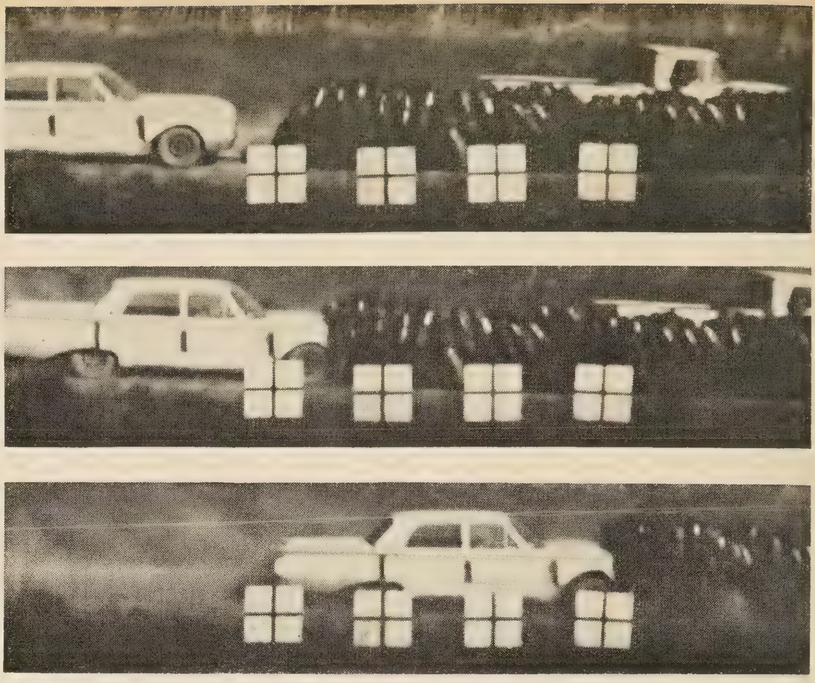


Figure 28.—42-m.p.h. head-on impact with a prototype old-tire barrier.

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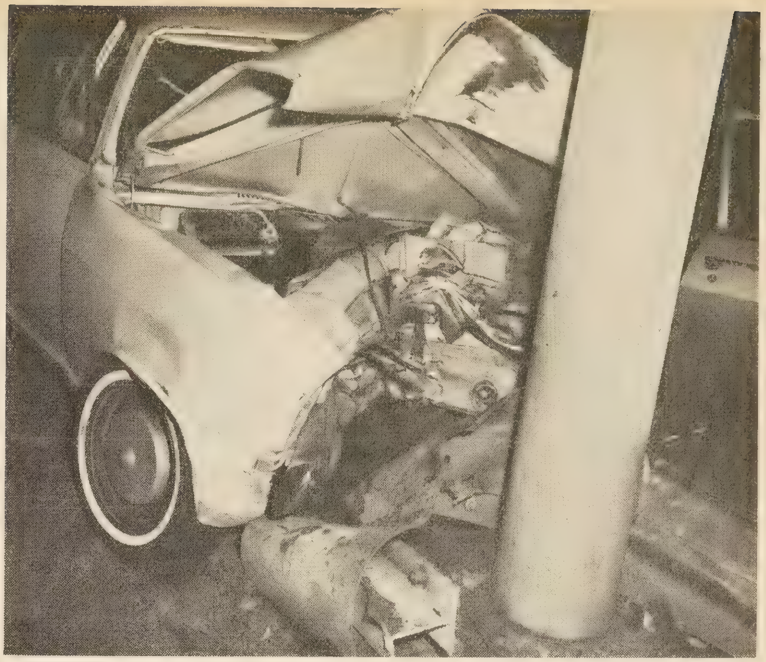

Fatal Accidents on Completed Sections of the Interstate Highway System, 1968–70

**BY THE OFFICE OF
TRAFFIC OPERATIONS**

**Reported by HAROLD R. HOSEA
Accident Record Analyst
Traffic Performance and Analysis Division**

Introduction

ANNUAL studies of the characteristics of fatal accidents on completed sections of he Interstate Highway System have been onducted by the Office of Traffic Operations, ederal Highway Administration, since 1968.[1])ata are obtained from police investigation eports supplied by State highway departients. Reports available for this purpose cover early 90 percent of the fatal accidents that ccurred on the Interstate System during the -year period.

The 1968 report (*1*)[2] contained a series of 2 statistical tables depicting characteristics of ie accidents, conditions under which they ccurred, and pertinent data concerning highays, vehicles, and drivers involved. Identical ibles summarizing the data for the 1969 and 970 studies are available on request. A list of iese tables appears at the end of this article. eferences (*2*) through (*6*) describe other ticles relating to fatal accidents on Interstate ghways.

Accident Patterns

The purpose of this report is to identify any substantial changes that have occurred during the 3-year period—1968 through 1970. Two-thirds of all fatal accidents reported involved only one vehicle in motion. Although this proportion has not changed appreciably, a further breakdown by type of single-vehicle accident does indicate some changes. As shown in table 1, the most common type of accident—the single vehicle which runs off the road—decreased slightly in relative importance. Pedestrian accidents, on the contrary, rose from 11.6 percent of the single-vehicle accidents in 1968 to 12.6 percent in 1970.

Of the pedestrians killed during the 3-year period, 31 percent were persons who had left their vehicles. The remainder were, in effect, trespassers, as pedestrians are generally excluded by statute or regulation from the Interstate System. Accidents involving trespassers have decreased somewhat in relative importance. They constituted 71.5 percent of the pedestrian fatalities in 1968 and 66.4 percent in 1970. Whether this trend resulted from more effective control of trespassers or an increase in carelessness among mororists who leave their vehicles is not known. Systematic data are not at hand, but police reports suggest that alcohol is an important factor in both types of pedestrian fatalities.

Rear-end collisions are the most common type of accident involving two or more moving vehicles. Between 1968 and 1970 both rear-end collisions and sideswipes showed slight declines in relative importance. Head-on collisions, on the contrary, rose from 33.0 percent of the multiple-vehicle accidents in 1968 to 38.2 percent in 1970.

It was assumed that the design of the Interstate System with its separated directional lanes would tend to eliminate head-on collisions, but they continue to be a problem. An analysis of these collisions shows a relative decrease in the proportions which resulted from vehicle operators driving in the wrong direction. Accidents caused by wrong-way drivers constituted 42.4 percent of the head-on collisions in 1968 (*3*), and 38.0 percent in 1970. Conversely, head-on collisions caused by out-of-control vehicles from opposing lanes rose from 53.1 percent in 1968 to 59.8 percent in 1970. Head-on collisions, designated as *other* in table 1, comprise a miscellaneous group of accidents such as, for example, the accident that occurs when an

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A limited amount of information based on 1967 accidents s also assembled, but the data are not entirely comparable :h those for later years.

Italic numbers in parentheses identify the references :ed on p. 227.

out-of-control vehicle reverses direction and collides with another in the same lane.

There has been virtually no change in the average number of fatalities and personal injuries per fatal accident. Considering all accidents as a group, averages are about 1.2 deaths and 1.1 nonfatal injuries per accident. Accidents involving two or more vehicles do, of course, result in higher fatality rates—about 1.5 or more deaths per head-on collision, for example.

The average dollar amounts of property damage per fatal accident for 1970, estimated at $3,089, increased about 9 percent over the comparable figure for 1968. Single-vehicle accidents increased nearly 15 percent, averaging $2,420 per accident in 1970. Rear-end collisions, typically the most costly, decreased from an average of $4,882 in 1968 to $4,641 in 1970. Damages resulting from head-on collisions increased about 10 percent—from $4,069 in 1968 to $4,414 in 1970. Variations in the economic loss resulting from different types of accidents reflect many divergent factors, particularly the vehicle types involved. Damages to a combination vehicle and its cargo, for example, can easily run well into five figures. Variations in ages, as well as makes and models, of the vehicles are also important, as damages to vehicles are limited to their current retail values for purposes of these studies.

Day and Time of Occurrence

Saturday was consistently the high point in the week for accidents—about a fifth of the total occurred on that day. Only about half that proportion occurred on Tuesdays. Slightly more than half the accidents occurred between 12:01 a.m. Friday and midnight Sunday.

The 1968 study indicated that the highest rate of fatal accidents involving only one moving vehicle occurred between 2 and 3 a.m. The peak hour for multiple-vehicle accidents was 11 p.m. to midnight. In 1970, however, the largest proportion of all accidents occurred between 1 and 2 a.m. Approximately 6.5 percent of the single-vehicle and 7.6 percent of the multiple-vehicle accidents occurred during this period when, as a rule, traffic volumes tend to be minimal. Of particular note, more than one of every 10 head-on collisions caused by wrong-way drivers occurred between 1 and 2 a.m.

There have been few changes in the relationships between accidents and light conditions. Considered as a group, 43 percent of the fatal accidents occurred during daylight hours, 52 percent at night, and the remainder at dawn or dusk. About a fourth of the nighttime accidents occurred on lighted stretches of highway. Disproportionate numbers of certain types of accidents occurred at night, notably, 75 percent of pedestrian fatalities, and 60 percent of rear-end collisions and head-on collisions caused by wrong-way drivers. The nighttime percentage of crashes caused by wrong-way drivers increased from 68 percent in 1968 to nearly 75 percent in 1970.

Table 1.—Fatal accidents on completed sections of the Interstate Highway System
type and year, 1968–70

Type of accident	1968–70		1968		1969		1970	
	Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
All accidents	9, 036	100. 0	2, 754	100. 0	3, 127	100. 0	3, 155	100. 0
Single vehicle	5, 998	66. 4	1, 842	66. 9	2, 056	65. 7	2, 100	66. 6
Multiple vehicle	3, 038	33. 6	912	33. 1	1, 071	34. 3	1, 055	33. 4
Single vehicle	5, 998	100. 0	1, 842	100. 0	2, 056	100. 0	2, 100	100. 0
Ran off the road	----------	78. 4	----------	79. 4	----------	78. 5	----------	77. 1
Overturn on road	----------	1. 7	----------	1. 7	----------	1. 4	----------	2. 1
Collision with parked vehicle	----------	5. 4	----------	5. 2	----------	5. 7	----------	5. 3
Pedestrian	----------	12. 2	----------	11. 6	----------	12. 4	----------	12. 6
Other	----------	2. 3	----------	2. 1	----------	2. 0	----------	2. 9
Pedestrian	733	100. 0	214	100. 0	254	100. 0	265	100. 0
Ex-occupants	----------	31. 1	----------	28. 5	----------	30. 7	----------	33. 6
Trespassers	----------	68. 9	----------	71. 5	----------	69. 3	----------	66. 4
Multiple vehicle	3, 038	100. 0	912	100. 0	1, 071	100. 0	1, 055	100. 0
Rear-end collisions	----------	44. 4	----------	45. 1	----------	44. 5	----------	43. 6
Head-on collisions	----------	36. 0	----------	33. 9	----------	35. 7	----------	38. 2
Broadside collisions	----------	7. 5	----------	7. 1	----------	8. 3	----------	7. 0
Sideswipes	----------	12. 1	----------	13. 9	----------	11. 5	----------	11. 2
Head-on collisions	1, 094	100. 0	309	100. 0	382	100. 0	403	100. 0
Wrong-way drivers	----------	40. 8	----------	42. 4	----------	42. 4	----------	38. 0
Out of control vehicles	----------	55. 8	----------	53. 1	----------	53. 9	----------	59. 8
Other	----------	3. 4	----------	4. 5	----------	3. 7	----------	2. 2

Weather and Highway Conditions

Year-to-year changes in the relationships between fatal accidents and weather or pavement conditions have been insignificant. Four out of five crashes occurred during clear or cloudy weather, 12 percent during rain, and 2 percent during snow. Fog or smoke was a significant factor in 3 percent, and high winds in another 2 percent.

Approximately 16 percent of the accidents occurred on wet pavements and 4 percent on snow or ice. A special circumstance was noted with respect to head-on collisions caused by vehicles out of control from opposing lanes. Disproportionate numbers—35 percent—of these crashes occurred on wet pavements, although no similar relationship was found with respect to single vehicles that run off the road—a type of accident somewhat similar in its initial stages.

Vehicles

In the majority of fatal accidents, detailed police investigation reports provide a reasonably adequate base for assigning primary responsibility. This poses no problem in two-thirds of the accidents since only one moving vehicle is involved. In virtually all head-on collisions and in most rear-end crashes, responsibility is apparent. In the relatively small numbers of other types of accidents, police narratives and diagrams are usually sufficient for assigning primary responsibility.

The 1968 study contains a comparison of the primary responsibility of different types of vehicles for fatal accidents with their importance in Interstate System traffic in terms of annual vehicle miles operated (*5*).

The data showed that passenger vehicles constituted 79.7 percent of the traffic and were primarily responsible for 81.4 percent of the fatal accidents. Percentages for propert-carrying vehicles were 20.3 and 18.6, respe-tively. Tractor-trailer combinations account for 10.2 percent of the traffic and were pr-marily responsible for 9.2 percent of the fat accidents (*2*). Vehicle-mile data were not ava-able for similar comparisons for later years.

The distribution of primary responsibili for accidents among drivers of different vehic types revealed numerous variations when i-dividual categories of accidents were co-sidered. For example, drivers of passeng vehicles were primarily responsible for di-proportionate numbers of head-on collisior broadsides, and sideswipes. Drivers property-carrying vehicles, on the contrar were over-represented in collisions with parke vehicles and rear-end collisions. Of the tot passenger-vehicle drivers responsible for fat accidents in 1970, 14 percent were primari responsible for head-on collisions; the co-responding proportion for tractor-trailer cor-binations was 5 percent and none of tl tractor-trailer crashes resulted from driving the wrong direction. Conversely, less than percent of the responsible drivers of passeng vehicles were the principal cause of rear-er collisions, but 27 percent of the drivers tractor-trailer combinations were responsib for this type of collision. Most comparisor of driver responsibility by vehicle type, hov ever, showed only minor variations from yea to year.

Police investigation reports are recognize as inadequate sources of information on vehic defects. Officers handling fatal acciden generally have neither the time nor th facilities for assembling such data. Only abou 10 percent of the reports refer to vehic defects and most of these mention tires—usually inadequate tread depth rather tha actual tire failure.

Vehicle Drivers

Sex and age of drivers

More than 85 percent of the drivers pr-marily responsible for the fatal accidents i

1970 were males, hence they were considerably over-represented compared with the sex distribution of all licensed drivers, among whom about three out of five are males. Any such comparison is misleading, however, as no account can be taken of *exposure;* males no doubt drive substantially more miles than fcmales. Females were primarily responsible for accidents involving only one vehicle somewhat more frequently than for those involving multiple vehicles.

In 1968, 33.7 percent of the males primarily esponsible for the fatal accidents were under 25 years of age as compared with 28.5 percent or females. A small change in these proportions s apparent from the 1970 data; the percentages were 31.1 and 30.0, respectively. Disproportionate numbers of younger drivers were primarily responsible for single-vehicle accidents—a third of the total—as compared with slightly more than a fourth for mutiple-vehicle accidents.

Compared with their representation in the otal licensed population, generally, drivers n the younger age groups were responsible or disproportionate numbers of accidents. An estimated one-fourth of all licensed drivers are under 25 years of age as compared with iearly a third who were primarily responsible or the fatal accidents. The proportion of male lrivers under 18 years of age primarily responsible for the accidents increased from 2.7 percent of the total in 1968 to 3.5 percent in 1970. During this period, single-vehicle accidents involving young drivers increased from 3.1 to 3.8 percent and multiple-vehicle accidents increased from 2.0 to 3.0 percent.

Drivers 65 years old or older were responsible for about 5 percent of the total accidents. 'emales were somewhat over-represented in his group — nearly 8 percent — as compared vith 5 percent for males in 1970. This difference increased in 1969 and 1970 over 1968. n 1970, females 65 years old and older vere more significantly over-represented in nultiple-vehicle accidents—10 percent as ompared with 6 percent for males. Although lrivers 65 years old and older were responsible or only about 5 percent of all the accidents, hey were involved in nearly 9 percent of the 970 crashes caused by driving the wrong vay on divided highways; in 1968 the percentage was even higher.

'hysical condition of drivers

Police reports for about 70 percent of the 970 accidents contained information on the physical condition of drivers primarily responsible. About 70 percent of these were described as normal. Four out of five of the *defects* reported were sleep and fatigue in a ratio of about 10 to 1. Sleep and fatigue were reported more frequently in collisions with parked vehicles and in rear-end collisions. About one of 10 was described as ill.

Sobriety of drivers

Police reports on three-fourths of the 1968 accidents contained information on drinking by drivers primarily responsible. Of the total reported, 32 percent were described as having been drinking and 9 percent as obviously intoxicated. No information on the extent of impairment was available on half the drivers reported as having been drinking, presumably due to the lack of tests or the unavailability of test results. The 1970 reports contained information on the sobriety of a slightly smaller proportion of the responsible drivers, but information on the extent of drinking was substantially the same as that for 1968.

In the 1968 report, it was noted that the 32 percent of the drivers reported as having been drinking was appreciably below the 50 percent figure widely quoted as the frequency of drinking drivers involved in fatal accidents. It was suggested that the type of travel typical of the Interstate System, together with the absence of taverns, bars, and similar establishments directly on these routes, may constitute a partial explanation of any existing differential.

Some evidence to support this hypothesis is available from an unpublished study of fatal accidents which occurred between April 1969 and March 1970 on all the highways in Federal Highway Administration Region 8.[3] Region 8 includes Alaska, Idaho, Montana, Oregon, and Washington.

This study indicated that for the combined highway systems in the region, half of the drivers responsible for fatal accidents, whose condition as to sobriety was reported, had been drinking. The proportion for the Interstate System—39 percent—was the lowest for any highway system. The proportion was still lower, only 33 percent, on rural sections of the System. The corresponding proportions of drinking drivers on the Federal-aid primary—other than Interstate—and Federal-aid secondary systems in Region 8 were 55 and 54 percent, respectively.

The incidence of drinking drivers varied among the different types of accidents on the Interstate System. Sobriety reports were available for 105 of the 153 drivers primarily responsible for the 1970 head-on collisions caused by wrong-way driving. Of these, 90 drivers (87 percent) were reported as having been drinking and 35 were described as obviously intoxicated—a substantial increase over the 74 percent reported in the 1968 study. Also, drinking was reported in a disproportionate number of collisions with parked vehicles.

Single-Vehicle, Off-the-Road Accidents

More than half the fatal accidents on the Interstate System during the 3-year period involved single vehicles that ran off the road. Four-fifths of these vehicles subsequently struck one or more fixed objects. There was, however, a progressive increase in the number of these vehicles that overturned after impacting a fixed object. This percentage rose from 32.8 in 1968 (*4*) to 42.2 in 1970 (table 2). Total overturns revealed a similar trend with an increase from 49.6 percent in 1968 to 59.2 percent in 1970.

When one or more fixed objects were struck, slightly more than a third of the vehicles first struck guardrails or dividers and about half that many struck bridge or overpass structures. There were minor year-to-year variations in the different types of fixed objects struck, but most variations showed up at random, because few accidents occurred where objects such as trees and fences were the first objects struck.

Of the 1,341 vehicles that left the road and struck a fixed object in 1970, more than two-fifths also struck a second object. This proportion was slightly higher than that for 1968. Seventy percent of the vehicles which first struck guardrails in the 1970 accidents subsequently struck another object, most frequently a bridge or an overpass structure. By contrast, only a fifth of the vehicles which first struck a bridge or an overpass subsequently struck another object; when a second impact did occur, it was most frequently with the same or a similar structure. In the 1968 study, the frequency of collisions with other objects following impacts with guardrails was slightly below the corresponding proportion in 1970.

Between 1968 and 1970, there were declines in the proportions of signs and light poles as first fixed objects struck. The reduction for signs was from 8.0 to 6.7 percent and for light poles from 5.2 to 3.5 percent. These changes are, of course, partly a reflection of corresponding increases in the proportions of other objects struck. For example, embankments were the first target in 7 percent of these accidents in 1968 and 12 percent in 1970.

(*Continued on p. 227*)

'able 2.—Characteristics of single-vehicle, off-the-road fatal accidents on completed sections of the Interstate Highway System, 1968–70

Type of accident	1968		1969		1970	
	Number	Percent	Number	Percent	Number	Percent
Total accidents, all types	1,462	100.0	1,616	100.0	1,619	100.0
Struck fixed object:						
Total	1,208	82.6	1,310	81.1	1,341	82.8
Overturned	480	32.8	601	37.2	683	42.2
Overturned only	245	16.8	299	18.5	276	17.0
Total overturns	725	49.6	900	55.7	959	59.2
Off the road only	9	0.6	7	0.4	2	0.1

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[3] Fatal Highway Accidents in Federal Highway Administration Region 8, April 1969–March 1970, Office of Traffic Operations, Federal Highway Administration, June 1971 (unpublished).

U.S. Interstate Highway Interchange Milepost Designators— An Investigation of Efficient Coding Methods

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BY THE OFFICE OF RESEARC

The experiment reported here was conducted to determine formats for presenting the milepost numbering system to designate interchanges. Thirteen alternative formats were tested by brief visual presentations of test slides. It was found that the letters and numbers on the slides in format 127A were recognized more often than those in the other formats.

ON the Interstate Highway System, all interchanges and exit ramps must be numbered. Since Interstate highways may have more than one exit ramp per mile, any numbering system must include a way to differentiate between such ramps. The milepost numbering system would require a suffix indicator to aid the driver in differentiating between ramps within one mile.

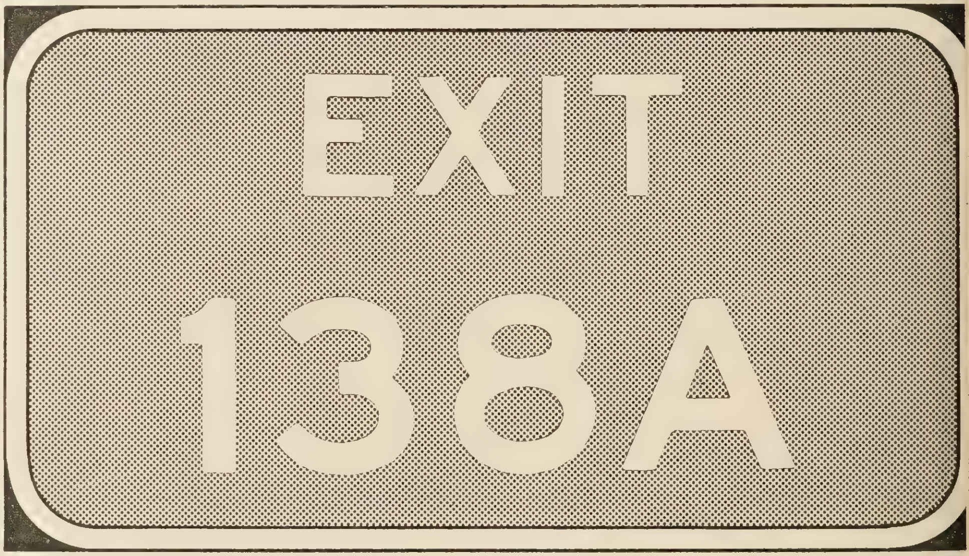
A study was made to determine an efficient format for numbering interchanges with the milepost system. The experiment neither attempted to ascertain the effectiveness of replacing the consecutive numbering system with the milepost numbering system, nor to determine the efficiency of retaining the consecutive numbering system in addition to the milepost system. Experimental evidence indicates that additional information, which is not highly correlated with the presented information, can produce a decrement in human performance (*1*).[1]

Method

Twenty employees at the Federal Highway Administration's Fairbank Highway Research Station, McLean, Va., served as subjects. They all had valid drivers' licenses, and those who required glasses while driving wore them during the experiment. The subjects' ages ranged from 19 to 62 years, and their driving experience ranged from 3 to 43 years. Therefore, it was assumed that the subjects used in the experiment were a representative sample of the general driving population.

Thirteen alternative formats of milepost information were used as follows:

127·1
127-1
127/1
1271 (yellow 1)
127♦1
127·A
127-A
127/A
127A (yellow A)
127A
127·a
127-a
127/a



Example of experimental format.

Five slides of each format were made, and each was presented twice to each subject. The slides, similar to the figure at the beginning of this article, had white letters and numbers on green backgrounds, with the exception of the two formats with a yellow character. Colors were matched as closely as possible to those in the Standard Interstate Color Ma ual (*2*). All numerals and uppercase lette were from Series E of the Standard Alphabe for Highway Signs (*3*); lowercase letters we also standard. Letter spacing conformed that recommended in the AASHO Manual f Signing and Pavement Marking (*4*).

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[1] Italic numbers in parentheses identify the references listed on p. 223.

The characters on the slides were drawn rom a random number table, and the slides vere presented in a random order—the osition of each of the 65 slides in each equence for each subject was due to chance. Each subject saw a total of 130 slides preented in two series of 65 slides. The slides vere shown by a Kodak Carousel projector vith a tachistoscopic shutter attached. They vere presented for a duration of 10 millisecnds with an interval of 5 seconds between ach presentation. The aperture setting was ept constant during the experiment.

While the subject was viewing the slides, a ilmstrip of an Interstate highway section vas shown simultaneously on the screen to simulate some of the actual visual conditions to which the driver is exposed on the road. Projectors were located behind the screen, and subjects were seated 8½ feet in front of the screen. The amount of ambient light in the room was kept constant.

Prior to the slide viewing each subject read the following instructions:

"This is an experiment to test the efficiency of different kinds of exit signs. You will be shown 130 slides. These will be flashed over a moving roadway scene. After each slide presentation, please say what 4 letters or numbers you saw. I will be recording your responses. For example, if you see 127.2, you will say 1272. You do not have to note any punctuation or figures in the sequence. You do not have to repeat "Exit" which will be on each slide. Please do this quickly because the length of time between the slides will be short. You will be given a rest break after the first 65 slides. The first slide that you see will not count."

In each sequence, the first slide shown to the subject was a duplicate of one of the test slides. This acquainted the subject with the length of slide exposure. For each format, each subject was assigned a score, which was the number of correct responses out of a possible 10.

able 1.—Mean scores for ranked alternative formats

Format	*Mean*
127A	7.75
127A (yellow A)	7.60
127·A	7.50
127-1	7.20
127/1	7.10
127♦1	7.05
1271 (yellow 1)	7.00
127·1	6.65
127/A	6.60
127-a	6.55
127·a	6.50
172-A	6.40
127/a	6.30

able 2.—Analysis of variance of alternative formats

Source	Degrees of freedom (*df*)	Mean squares (*MS*)	*F*
Format	12	4.60	[1] 2.31
Subjects	19	68.65	[1] 34.52
Formats×subjects	228	1.99	--------
Total	259	7.00	--------

[1] $p < .05$.

Results

Mean scores for the alternative formats are listed in rank order in table 1. A treatment by subjects (*5*) analysis of variance was performed on the data, a summary of which is given in table 2. The main effects of the alternative formats are significant. To evaluate where there is a significant difference between individual pairs of means, the critical difference technique (*5*) was applied to the means presented in table 2. As is shown in table 3, there is a significant difference between 18 of the 78 simple effects.

Discussion

The results of the study indicate that subjects recognized format 127A more often than any other format, although there is no statistical significance between this format and formats 127A (yellow A) and 127·A. Format 127A does not differ significantly from formats 127-1, 127/1, 127♦1, and 1271 (yellow 1); however, a reduction of 5 percent recognition seems to be a practical cutoff. It cannot be said with certainty that format 127A is better than 127A (yellow A) or 127·A. However, format 127A differs significantly from more of the other formats than do 127A (yellow A) or 127·A. As shown in table 2, the three formats with lowercase letters were recognized, in general, less often than both the uppercase letter and tenths-of-miles formats.

The findings of this experiment suggest that either format 127A or formats 127A (yellow A) or 127·A would be more easily recognized by the driver on an exit sign than the other 10 formats.

REFERENCES

(*1*) *The Role of Stimulus Redundancy in Concept Identification*, by Lyle E. Bourne, Jr., and Robert C. Haygood, Journal of Experimental Psychology, vol. 58, No. 3, 1959, pp. 232–238.

(*2*) *Manual for Signing and Pavement Marking—Standard Interstate Colors*, AASHO, 1961.

(*3*) *Standard Alphabets for Highway Signs*, U.S. Department of Transportation, FHWA, February 1971.

(*4*) *Manual for Signing and Pavement Marking of the National System of Interstate and Defense Highways*, AASHO, 1970, p. 27.

(*5*) *Design and Analysis of Experiments in Psychology and Education*, by E. F. Lindquist, Houghton Mifflin Co., Boston, 1953.

Table 3.—Table of differences between individual pairs of means

	127A(c)	127·A	127-1	127/1	127♦1	1271(c)	127·1	127/A	127-a	127·a	127-A	127/a
127A	0.15	0.25	0.55	0.65	0.70	0.75	[2] 1.10	[2] 1.15	[2] 1.20	[2] 1.25	[2] 1.35	[2] 1.45
127A(c) [1]	----------	.10	.40	.50	.55	.60	[2] .95	[2] 1.00	[2] 1.05	[2] 1.10	[2] 1.20	[2] 1.30
127·A	----------	--------	.30	.40	.45	.50	.85	[2] .90	[2] .95	[2] 1.00	[2] 1.10	[2] 1.20
127-1	----------	--------	--------	.10	.15	.20	.55	.60	.65	.70	.80	[2] .90
127/1	----------	--------	--------	--------	.05	.10	.45	.50	.55	.60	.70	.80
127♦1	----------	--------	--------	--------	--------	.05	.40	.45	.50	.55	.65	.75
1271(c) [1]	----------	--------	--------	--------	--------	--------	.35	.40	.45	.50	.60	.70
127·1	----------	--------	--------	--------	--------	--------	--------	.05	.10	.15	.25	.35
127/A	----------	--------	--------	--------	--------	--------	--------	--------	.05	.10	.20	.30
127-a	----------	--------	--------	--------	--------	--------	--------	--------	--------	.05	.15	.25
127·a	----------	--------	--------	--------	--------	--------	--------	--------	--------	--------	.05	.20
127-A	----------	--------	--------	--------	--------	--------	--------	--------	--------	--------	--------	.10

[1] (c) denotes yellow color.
[2] $p < .05$.

Digest of Recent Research and Development Results

Reported by the Implementation Division, Office of Development

The items reported here have been condensed from highway research and development reports, predominantly of Federally aided studies. Not necessarily endorsed or approved by the Federal Highway Administration, the items have been selected both for their relevancy to highway problems and for their potential for early effective application.

Each item is followed by source or reference information. Reports with an "NTIS" reference number are available in microfiche (microfilm) at 95 cents each or in paper facsimile at $3 each from the National Technical Information Service (NTIS), 5285 Port Royal Road, Springfield, Va. 22151.

PRECAST-PRESTRESSED CHANNELS PROMISED NEW BRIDGE ECONOMIES

A recently developed bridge construction technique using precast-prestressed channels has been developed which promises to reduce construction costs in comparison to bridges currently used in Missouri for span lengths of 30 to 50 feet. In place of the conventional superstructure the bridge has a cast-in-place deck over the precast-prestressed channels. Costs of conventional superstructures of comparable span length now in service indicate significant savings are possible for the new system. Actual construction of several of the new method bridges will provide more accurate information on their economic superiority and structural performance.

Study of a Proposed Precast-Prestressed Composite Bridge System, Missouri State Highway Department report, Research Study 67-1.

SKEWED CONTINUOUS SLAB BRIDGE DECK ANALYSIS BY COMPUTER

More exacting design analysis and better understanding of skewed slab bridge decks can be obtained with computer programs developed in a recent study. This study takes account of continuous slabs of variable rigidity with or without edge beams at any angle of skewness, and with any combination of span ratios. Orthogonal conditions are imposed to minimize the error function. In their present forms the programs can be used on four-span continuous slabs, but any number of spans and approximations are possible by changing the common dimensions. If the programs (there are three) are applied to integral abutment structures, separate investigations of in-plane forces is necessary since the programs do not take these into account.

Analysis of Bridge Deck Slabs, Kansas State Highway Commission report, Research Study 66-1. NTIS No. PB-175741.

LATERAL DISTRIBUTION OF LOAD FOR PRESTRESSED CONCRETE BOX BEAM BRIDGES

Present load distribution factors used for this type of bridge can be overly conservative, according to results of a study using field tests, laboratory model studies, and theoretical calculations. Generally, the new factors, based on moving-load tests using an HS-20 design vehicle, reflect the influence of the curbs and parapets on load distribution, and range from 6.0 to 7.5, whereas the corresponding present design value is 5.5 for stringer distribution, and 7.0 for concrete box girder distribution. New distribution factors are proposed for exterior and interior beams for 2-lane and 3-lane bridges which have either four or five beams.

Structural Behavior Characteristics of Prestressed Concrete Box-Beam Bridges, June 1969, Pennsylvania Department of Transportation, Study No. 64-6. NTIS No. PB-183921.

CONCRETE BRIDGE DECK CRACKING

Concrete bridge deck cracking studies on four separate bridge construction jobs were recently completed. Significant evaluations of construction practices, air entrainment, attention to curing, and weather conditions, with respect to their effect on concrete deck cracking, are as follows:

- Adverse weather has more effect on deck cracking than do adverse construction practices. However, adverse weather effects can be minimized by good construction practices.
- Poor initial curing is a major contributing cause of excessive deck cracking.
- Membrane curing compounds reduce deck cracking when concrete is placed during periods of high wind or low humidity.
- Adverse cracking can be caused by applying water or grout to the concrete surface during finishing operations.

Factors Affecting the Durability of Concrete Bridge Decks, Interim Report Pt. No. 2, California Division of Highways, Research Study No. D-3-29. NTIS No. PB-189337.

MICROWAVE HEATING OF TEST SAMPLES IS FASTER AND CUTS COSTS

Recent report evaluations of microwave heating in tests of highway materials indicate the process to be 10 times faster than conventional ovens, and costs less. Colorado anticipates close to $500 per month savings during the construction season from use of the electromagnetic wave ovens in each of their field districts. Test evaluations of the unit involved certain modifications to make it suitable for certain highway materials. Possible applications include moisture determinations for plastic concrete, sand, coarse aggregate, and embankment samples; plus tests of L.L. and P.I. samples. Certain limitations on use of the oven are appropriate where critical tests of the dried material could be affected by high temperatures created within some samples.

Use of Microwave Oven for Rapid Drying of Aggregate Samples, Colorado Department of Highways report, Study No. 1474. NTIS No. PB-190602.

SYNTHETIC AGGREGATE CLASSIFICATION REVISION

As a result of their latest studies, Texas Transportation Institute researchers have considered it desirable to revise the recommended synthetic aggregate classification system for highway construction which they developed from earlier studies. The classification system was intended for and offered as a supplement to existing aggregate requirements. The revisions appear in a four-page leaflet containing two tables. Table 1 identifies, by appropriate test criteria, two aggregate classes and three groups within each class. Table 2 shows for each highway (aggregate) function—e.g., surface treatments, base materials—the permissible coarse aggregate group, as defined in table 1.

A Recommended Synthetic Coarse Aggregate Classification System, August 196 Texas Highway Department, summary report on Research Study 2-8-65-81

LONG-TERM ASPHALT DURABILITY STUDIED

The importance of proper design of the mix and proper construction of asphalt-concrete pavements is emphasized by the results of recently completed research on asphalt durability. The amount of asphalt hardening, which was highly variable, was found to be closely related to the void content of the pavement samples. This finding shows the need for proper control of void content, or voids filled with asphalt, for optimum asphalt durability. Significantly, large differences in void content and related asphalt hardening appeared within many of the projects from the replicate tests on random pavement samples, thus illustrating the fallacy of judging asphalt durability from limited pavement samples.

These are but some of the findings developed from the Federal Highway Administration's study of the hardening of asphalt cements from 29 widely different sources that had been in service in pavements for 11 to 13 years. More than 1,900 pavement cores from over 300 randomly selected test sites in 53 paving projects were analyzed. Continuing analysis of the accumulated data is expected to provide quantitative evaluation of some of the interactions affecting the life of a pavement, as well as guidance for better mixture design and construction practices, and to be of value for the design of future research studies concerned with asphalt durability.

Asphalt Hardening: Fact and Fallacy by J. York Welborn, PUBLIC ROADS, A JOURNAL OF HIGHWAY RESEARCH, vol. 35, No. 12, February 1970. *Changes in Fundamental Properties of Asphalts During Service in Pavements.* Final Report on FHWA Contract FH–11–6147. NTIS No. PB–190841.

FAIL-SAFE HIGHWAY FIXTURES

Current progress is rapidly providing a highway environment that is safer for the user. Two recent papers emphasize accident survivability as the main objective of highway design and structural concepts that deal with *run-off-the-road* accidents. They begin with removal of hazardous obstructions, and go on to prescribe for errant vehicles either redirecting devices, or effective techniques for absorbing vehicle impact energy. The reports discuss frangible, breakaway, and other types of fail-safe structural features in roadside appurtenances. A notable example of the application of these concepts is the test mounting of four 20-foot-high 1,500-pound posts on typical *breakaway type slip-base supports* for an overhead sign bridge. Test results from vehicle impact with these posts indicate an average deceleration of only 2 to 3 g's, with relatively minor damage to the vehicle and no collapse of the bridge. These and related developments contribute to the possible significant reduction of an annual economic loss that is equivalent to about 12 cents per gallon of gasoline consumed by our motor vehicles today.

"Fail-Safe" Structures for Highway Safety, by F. J. Tamanini, PUBLIC ROADS, A JOURNAL OF HIGHWAY RESEARCH, vol. 36, No. 6, February 1970. *Energy-Absorbing Roadside Crash Barriers,* by F. J. Tamanini, Cnief, and John G. Viner, Structural Research Engineer. Structures and Applied Mechanics Division, Federal Highway Administration, reprinted from Civil Engineering, January 1970.

BRIDGE DECK REPAIRS WITH EPOXY MATERIALS

Epoxy seals are of questionable benefit in protecting bridge decks rom deterioration resulting from spalling and hollow planes according o a study of sealing practices used in Kansas. Thin coats of epoxy resin ith angular aggregates were found to be full of pinholes. When heavier pplications of epoxy and small rounded aggregates were used, pinholes ere prevented but blistering occurred instead. The blistering correlated ith rising temperatures and falling barometric pressures at time of pplication.

An epoxy mortar patching mixture, for replacing unsound concrete aterials, performed acceptably when absorption was less than 1 ercent. This requirement was met using five parts sand, with one part ach of epoxy and cement. Even less absorption occurred with only our parts sand in the mix. Successful use of the satisfactory mix requires complete removal of all unsound concrete from the area to be atched.

Bridge Deck Deterioration Study—Part 9, Epoxy Resin Seal Coats and Epoxy Mor- r Patching for Bridge Decks, Kansas State Highway Commission report, NTIS B–192470.

NONDESTRUCTIVE FIELD TESTING OF WELDS

A recent study reports the development of ultrasonic weld inspection devices and portable radiographic equipment which in combination can reduce the cost of radiographic inspection to one-tenth of that now required. Essential to this cost saving is the ultrasonic preliminary screening of good welds from questionable ones to eliminate most of the costly radiography currently required. The self-contained field X-ray equipment includes units capable of radiography through steel in the range of thickness up to 1½–2 inches with a single pulse. Highway department use of these devices can be expected to provide better quality, speed up inspection processes, and reduce cost by increasing the production rate and reducing the required number of inspection personnel. Operation of the field portable system requires only one man with no special training.

Non-Destructive Tests for Welds in Highway Structures, Ohio Department of Highways, Study No, EES–261.

NOCTURNAL TESTING OF SKID RESISTANCE

Night-time testing of pavement skid resistance has definite advantages on heavily traveled highways This conclusion is based on experience in testing conducted between midnight and 6 a.m. on heavily traveled, multiple-lane, high-speed Interstate highways in the Baltimore-Washington metropolitan area, by the Maryland State Roads Commission's Bureau of Research. The lighter traffic density and better visibility of warning signals at night resulted in a safer testing operation and minimized interference to traffic. An HPR project is underway to explore the possible added advantage of more consistent tire and pavement temperatures during night-time hours.

Maryland State Roads Commission, Bureau of Research.

EVALUATION OF TRAFFIC INTERSECTION CONTROL NEEDS

A digital recording device recently developed can collect vehicle volume and delay characteristics at intersections in a form directly applicable to high-speed data processing techniques. If made available to traffic engineers, this capability for multichannel recording of traffic characteristics could be used effectively to select stop-and-go type traffic controls at simple low-volume intersections and diamond interchanges, or to evaluate the performance of controls at existing installations. Computer programs have been developed for data reduction and analysis. The research supports warrants applied by the Texas Highway Department for traffic-actuated signals in urban areas, and facilitates before-and-after evaluation studies.

Evaluation of Traffic Control at Highway Intersections, Texas Highway Department, Research Study No. 78.

ASPHALTIC CONCRETE ADDITIVES AND ADMIXTURES

The influence of various additives and admixtures on the performance of asphalt concrete surface courses has been studied during the past 5 years on 14 New York highway test pavements. Admixtures tested included asbestos and talc fibers, crumb and latex rubber products, and hydrated lime. Visual observations, including core samples of test sections compared with control sections, indicated that these admixtures have little or no effect on the performance of the State's standard high-quality surface-course mixtures used in this investigation. However, the authors pointed out possible beneficial effects of some admixtures, particularly hydrated lime and asbestos, with lower quality aggregates, or of mixtures designed for special applications.

Additives and Admixtures for Asphalt Concrete—Asbestos, Rubber, Talc, and Hydrated Lime, State of New York Department of Transportation, Study No. 20–5.

Highway Research and Development Reports Available from the National Technical Information Service

The following highway research and development reports are available from the National Technical Information Service (formerly the Clearinghouse for Federal Scientific and Technical Information), Sills Building, 5285 Port Royal Road, Springfield, Va. 22151. Paper copies are priced at $3 each and microfiche copies at 95 cents each. To order, send the stock number of each report desired and a check or money order to the National Technical Information Service. Prepayment is required.

Other highway research and development reports available from the National Technical Information Service will be announced in future issues.

STRUCTURES

Stock No.	
PB 199038	The Development of Ultrasonic Nondestructive Testing Instrumentation to Measure Pavement Thickness.
PB 199078	An Algebraic Equation Solution Process Formulated in Anticipation of Banded Linear Equations.
PB 199097	Instrumentation for Measurement of Axial Load in Drilled Shafts.
PB 199110	Development of Sonic and Ultrasonic Power Devices for Application in Highway Engineering. Vol. 1
PB 199111	Vol. 2
PB 199113	Determination of Water Accumulation Adjacent to and in Normal Earth Embankments Constructed in Pierre Shale.
PB 199132	Granular Base Materials for Flexible Pavements (Final Report).
PB 199204	Adaptation of the General AASHO Road Test Equation to Arkansas Conditions.
PB 199352	Presplitting.
PB 199354	Pavement Material Properties as Related to Skid Resistance.
PB 199356	Frictional Characteristics of Pavement Surfaces (Final Report).
PB 199359	An Experimental Self-Stressing Pavement, Route 2, Glastonbury 3 (Final Report).
PB 199419	Operation and Installation Instructions for an Energy Absorbing Bridge Rail System.
PB 199420	Energy-Absorbing Bridge Rail (Fragmenting Tube).
PB 199466	Skid Resistance Study Interim Report No. 1.
PB 199467	Evaluation of Factors Affecting the Tensil Properties of Lime-Treated Materials.
PB 199468	Field Testing of Concrete Slab and Girder Bridges.
PB 199470	A Laboratory Study of the Relation of Stress to Strain for a Crushed Limestone Base Material.
PB 199530	Pavement Slipperiness (Project 930-043), Interim Report Covering Tapley Decelerometer Data.
PB 199531	Loading History and its effects on Highway Bridges (Pilot Study).
PB 199779	A Skid Resistance Study of Georgia Pavements.
PB 199780	Dynamic Analysis of Discrete-Element Plates on Nonlinear Foundations.
PB 199781	Pavement Cutting to Improve Skid Characteristics of Pavements.
PB 199783	Pavement Design and Performance Study Phase B: Deflection Study (Interim Report No. 2). A method for evaluating the structural performance of subgrades and/or the overlying flexible pavements.
PB 199784	Fatigue of Beams with Welded Cover Plates Under Variable Loads.
PB 199790	The Florida Skid Trailer.
PB 199811	An Experiment in Pavement Slab Design.
PB 199812	Applicability of Braking Control Systems to Highway Vehicles (Final Report).
PB 199988	Behavior of Concrete Slab and Girder Bridges.
PB 200067	Fatigue Life of Bridges under Repeated Highway Loadings.
PB 200084	Criteria for Yielding Highway Sign Supports (Final Report).
PB 200085	Prestressing Duct Curvature Forces (Final Report).
PB 200087	URS Free Field Soil Stress Gauge—Design, Construction and Evaluation.
PB 200413	Instability of Horizontally Curved Members, Buckling of Unstiffened Curved Plates.
PB 200415	Thermal Expansion and Contraction of Concrete Pavements in Utah (State Study No. 915).
PB 200463	Clifton-Highline Canal Experimental Project No. 1 70-1(14)33 (Third Interim Report).
PB 200464	Crawford-South Experimental Project S 0125(9), (Third Interim Report).

MATERIALS

Stock No.	
ORO-3842-2	Radioisotope X- and Gamma-Ray Methods for Field Analysis of Wet Concrete Quality (Final Report).
ORO-3842-3	Instrument Manual for Prototype Wet Concrete Analyzer.
PB 194397	Statistical Quality Control—Phase VI, Soils: Statistical Specifications for Pug Mill Mixed Material.
PB 199096	Typical Moisture-Density Curves Part A, T-180 Compaction.
PB 199098	Basic Properties of Seal Coats and Surface Treatments (Final Summary Report).
PB 199099	Investigation of Alternative Chemical Treatments for Controlling Expansive Soil in Roadways in Western So. Dakota.
PB 199107	Sodium Silicate Stabilization of Soils—A Review of the Literature.
PB 199116	Study of Fly Ash as a Material for Use in Concrete.
PB 199173	Material Quantities for Seal Coats and Surface Treatments.
PB 199211	Shrinkage-Cracking Characteristics of Structural Lightweight Concrete (Final Report)
PB 199212	Nonbloated Synthetic Aggregate Concrete.
PB 199355	Air Pollution from Hot Mix Plants.
PB 199376	Concrete-Polymer Materials for Highway Applications—Progress Report No. 1.
PB 199422	Remote Sensing and Development of Annotated Aerial Photographs as Master Soil Plans for Proposed Highways (Final Report).
PB 199429	A Quick Setting Silico-Phosphate Cement.
PB 199469	Bridge Deck Condition Survey. Part I—Outline of the Project and Findings from the Survey.
PB 199500	Crack Control in Cement-Treated Basis (Draft of Final Report).
PB 199718	Effect of Moisture on Typical Virginia Surface Treatment Materials.
PB 199791	Corrosion of Corrugated Metal Pipe (Final Report).
PB 199792	Evaluation of Epoxy Compounds as a Material for Patching and Protecting Concrete (Final Report).
PB 199793	Study of Bituminous Surface Treatments in Virginia. Phase II — Summer 1964: Distribution Characteristics of Materials — Effectiveness of One Size Aggregate — Setting Time.
PB 199794	Analysis of Factors that Significantly Influence the Quality of Bituminous Surface Treatments.
PB 199813	The Wearing Characteristics of Mine Aggregates in Highway Pavements.
PB 200077	Analysis of Fatigue and Fracture of Bi minous Paving Mixtures (Final Report Phase I).
PB 200414	Sonic and Conventional Measurement Rigid Pavement Thicknesses.
PB 200462	Highway-Problem-Oriented Photo Interp tation Using Panchromatic, Normal Col and Infrared Color Air Photos.

TRAFFIC

PB 199079	State of the Art Related to Real-Time T fic Information for Urban Freeways.
PB 199106	An Analysis of Traffic Operation on Mark Twain Expressway at I-270 in Louis County, Study 70-2.
PB 199108	Warning Light Study. A Study of the Effect on Driver Behav of Operating Emergency Amber Lights.
PB 199271	Merging Control System (Final Report) Vol. 1 — Pacer System Analysis a Design.
PB 199272	Vol. II — Pacer System Software.
PB 199273	Vol. III — Pacer System Program Listi
PB 199274	Vol. IV — Pacer System Performance Da
PB 199275	Vol. V — Pacer System Performance E uation.
PB 199276	Vol. VI — Preliminary Studies.
PB 199277	Vol. VII — Adaptive System Analysis a Specifications.
PB 199278	Vol. VIII — Green Band Design.
PB 199279	Vol. IX — Green Band Performance Da
PB 199280	Vol. X — Green Band Performance Eva ation.
PB 199281	Merging Control System — Summary. (Fi Report)
PB 199340	Traffic Systems Reviews and Abstracts. No. 41 — January 1971.
PB 199341	No. 42 — February 1971.
PB 199342	No. 43 — March 1971.
PB 199343	No. 44 — April 1971.
PB 200075	Last issue of series — May 1971.
PB 199421	Vehicle Classifying Counter.
PB 199423	Development of Stream Flow Methodolo Vol. 1
PB 199424	Vol. 2
PB 199433	A Probabilistic Approach to Tra Problems: Phase II (Final Report).
PB 199471	Right Turn on Red Accident Stud Minnesota Highway Department.
PB 199846	Statistical Studies in Traffic Flow Proble Vol. 1
PB 199847	Vol. 2
PB 200315	Effect of Lane Placement of Truck Traffic Freeway Flow Characteristics (Fi Report).

ENVIRONMENT

Stock No.	
PB 198261	Alabama Highway Research—Location teria for Highway and School Plann Part A.—Findings, Conclusions, Recommendations.
PB 198262	Part B.—Theoretical and Methodologi Framework.
PB 199114	Toxicity of 2,4-D and Picloram to Fr Water Algae.
PB 199125	Visual Values for Highways. Development of Relative Visual Values Esthetic Merit for Highway Plann and Design. Vol. 1
PB 199126	Vol. 2
PB 199353	Combination Treatments for Control Wild Garlic and Common Milkweed.
PB 199358	Highway Accident Costs and Rates in Tex
PB 199360	CIPC-2,4-D Combinations for Control 2,4-D-Resistant Monocot Species.
PB 199782	Optimal Design of a Surface Transit Syst (Final Report).
PB 200101	Flood Routing Through Storm Drain Unsteady Free-Surface Flow in a Sto Drain Project.
PB 200417	Threshold Noise Levels.
PB 200465	Study Design: Highway Transportation a the Quality of the Physical Environme

FIELD TESTING

tock No.	
B 199077	Nuclear Test Equipment Investigation Lane-Wells Road Logger. Part I.
B 199357	Field Evaluation of Skid Resistant Surfaces.
B 200416	Statistical Methods for the Quality Control of Steam Cured Concrete (Final Report).

RESEARCH IMPLEMENTATION

Stock No.	
B 198590	Electronic Computer Program for Stereo-comparator Coordinate Reduction (TIES Computer Program No. R-0100).
B 198592	Electronic Computer Program for Analytical Strip Triangulation (TIES Computer Program No. R-0200).
B 198594	Electronic Computer Program for Analytical Strip Triangulation and Adjustment (TIES Computer Program No. R-0300).
PB 200418	A Systematic Procedure for Minimum Cost Design of Highway Bridges.
PB 200082	Development of Photogrammetric Methods in Right-of-Way Operations.

PLANNING

Stock No.	
PB 190921	Highways I: The Basis for Planning.
PB 196005	Non-User Factors in Highway Planning.
PB 198648	Feasibility and Evaluation Study of Reserved Freeway Lanes for Buses and Carpools.
PB 198782	Physiographic Zones in Georgia.
PB 199485	The Collection and Use of Truck Weight Data.
PB 198770	Development of a Procedure to Estimate Parking Demand in Urban Areas, GHD Research Assistance Project No. 1-70 (Final Report).
PB 199810	Data Requirements for Determining Impact of Highway Investment on Regional Economies.
PB 200066	Planned Residential Environments.
PB 200069	Estimating Land and Floor Area Implicit in Employment Projections. Vol. 1
PB 200070	Vol. 2
PB 200073	The Impact of Transportation Staging on Metropolitan Growth.

ADMINISTRATION

Stock No.	
PB 200074	Proposed Highway Code for Georgia—Phase I (Final Report).

Fatal Accidents on Completed Sections of the Interstate Highway System, 1968–70

(*Continued from p. 221*)

Whether the installation of breakaway gns and light poles has any bearing on these omparisons is unknown as the accident ports do not normally contain this information. Further, the reduction in the importance of these two objects may reflect a duction in fatal accidents as a result of eakaway features. As figures on total ntacts with such structures are not available, eir significance cannot be evaluated.

According to the data in table 2, there has en no substantial decline during this 3-year riod in fatal accidents caused by off-the-ad vehicles striking roadside objects on the terstate System. From the data available, wever, the relative importance—at any e time or over the entire period—of road sign and driver behavior cannot be termined.

List of Tables

The following tables are available for the ars 1968, 1969, and 1970. The 1968 set is ntained in the first article listed in footnote 1 d reprints are available on request. This list scribes the type of information contained in ch table rather than the formal titles:

1. Accident types, fatalities, injuries, and property damage.
2. Accident types and light conditions.
3. Relationships between vehicle travel, accidents, fatalities, and injuries by type of vehicle (1968 only).
4. Types of vehicles involved in each type of accident.
5. Types of accidents in which each vehicle type was involved. (Tables 4 and 5 contain converse percentage distributions.)
6. Age and sex of drivers.
7. Condition of drivers.
8. Sobriety of drivers.
9. Age and sobriety of drivers.
10. Characteristics of single-vehicle, off-the-road accidents.
11. First fixed objects struck in single-vehicle, off-the-road accidents.
12. First and second fixed objects struck in single-vehicle, off-the-road accidents.

REFERENCES

(*1*) *Fatal Accidents on Completed Sections of the Interstate Highway System, 1968,* by Harold R. Hosea, PUBLIC ROADS, vol. 35, No. 10, October 1969.

(*2*) *Fatal Accidents Involving Tractor-Trailer Combinations in Rear-End Collisions on Completed Sections of the Interstate System, 1968,* by Harold R. Hosea, PUBLIC ROADS, vol. 35, No. 11, December 1969.

(*3*) *Fatal Head-On Collisions on the Interstate System, 1968, Caused by Wrong-Way Drivers,* by Harold R. Hosea, PUBLIC ROADS, vol. 35, No. 12, February 1970.

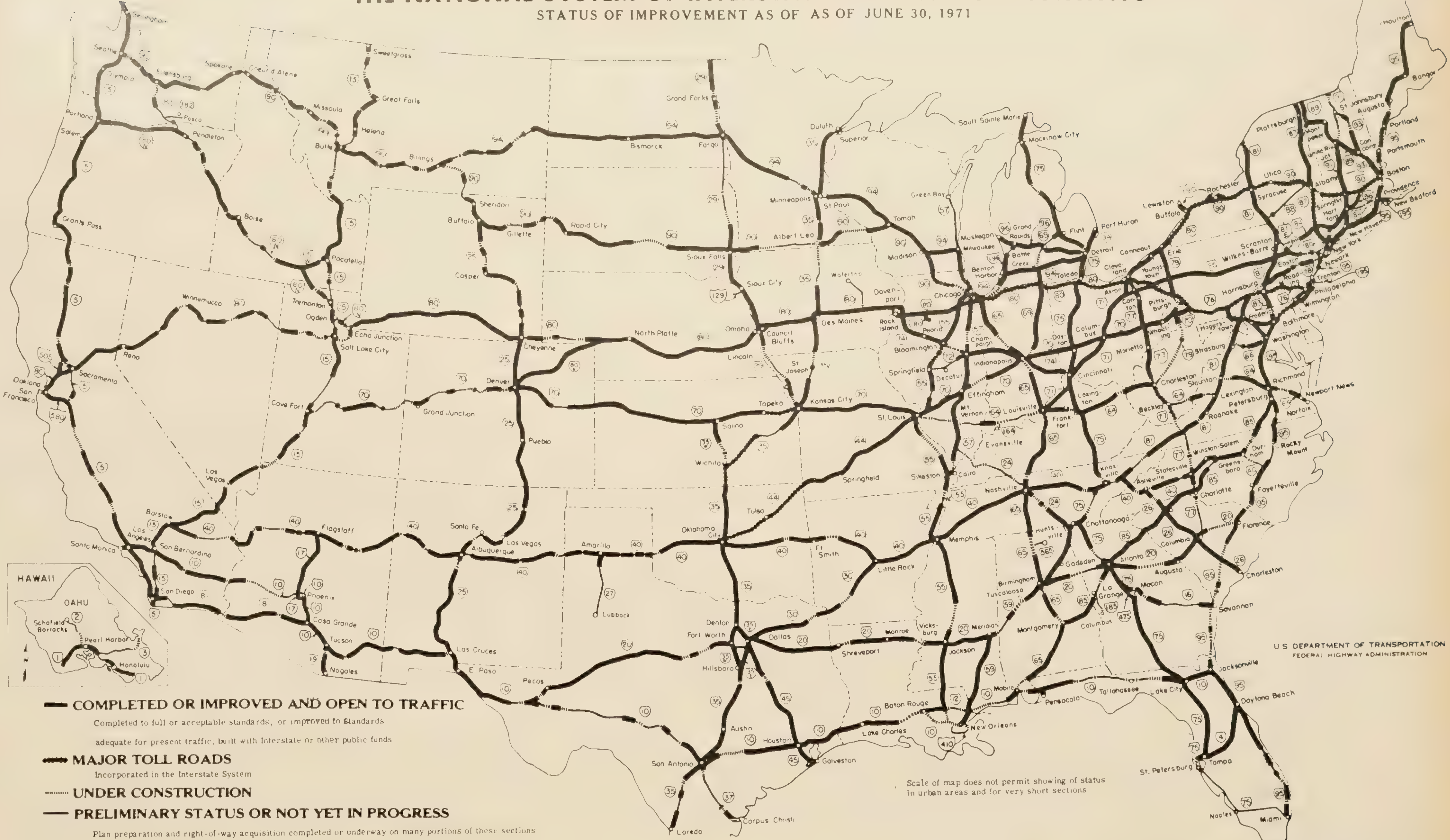
(*4*) *Fatal Collisions with Fixed Objects on Completed Sections of the Interstate Highway System, 1968,* by Harold R. Hosea and J. N. McDonald, PUBLIC ROADS, vol. 36, No. 1, April 1970.

(*5*) *Differences in Fatal-Accident Patterns by Type of Vehicle on the Interstate System,* by Harold R. Hosea, PUBLIC ROADS, vol. 36, No. 2, June 1970.

(*6*) *Fatal Accidents on Completed Sections of the Interstate Highway System, 1968–69,* by Harold R. Hosea, PUBLIC ROADS, vol. 36, No. 6, February 1971.

THE NATIONAL SYSTEM OF INTERSTATE AND DEFENSE HIGHWAYS

STATUS OF IMPROVEMENT AS OF AS OF JUNE 30, 1971



U S DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

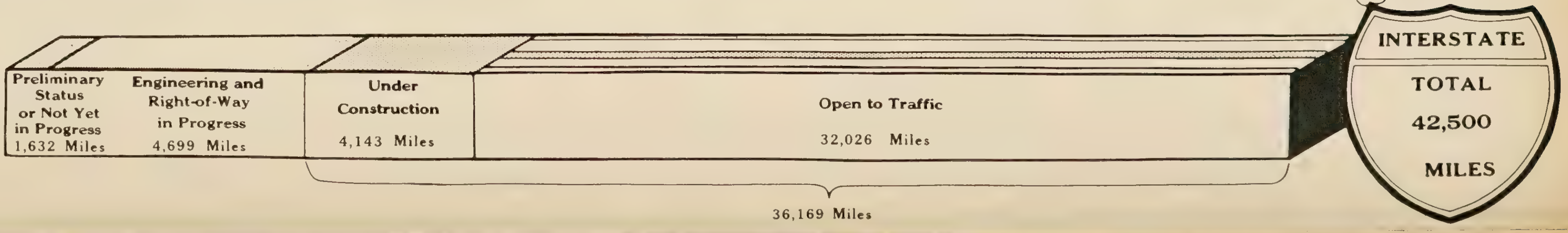
Scale of map does not permit showing of status in urban areas and for very short sections

COMPLETED OR IMPROVED AND OPEN TO TRAFFIC
Completed to full or acceptable standards, or improved to standards adequate for present traffic, built with Interstate or other public funds

MAJOR TOLL ROADS
Incorporated in the Interstate System

UNDER CONSTRUCTION

PRELIMINARY STATUS OR NOT YET IN PROGRESS
Plan preparation and right-of-way acquisition completed or underway on many portions of these sections



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A list of articles in past issues of Public Roads *and title sheets for volumes 24–35 are available upon request from the Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. 20590.*

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Fatal and Injury Accident Rates on Federal-Aid and Other Highway Systems, 1968. 45 cents.

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